Scottish Crop Research Institute

Annual Report 2003/2004

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Governing Body

Accountants : PriceWaterhouseCoopers LLP, Kintyre House, 209 West George Street, Glasgow G2 2LW.

Solicitors : Thorntons WS, 50 Castle Street, Dundee DD1 3RU.

Banking : Bank of Scotland, P.O. Box 9, 2 West Marketgate, Dundee.

Patent Agents : Murgitroyd & Co, 373 Scotland Street, Glasgow.

Scottish Crop Research Institute
Invergowrie, Dundee DD2 5DA, Scotland, UK.

A charitable company (No. SC006662) limited by guarantee No. 29367 (Scotland) and registered at the above address.

Telephone : +44 (0)1382 562731
Fax : +44 (0)1382 562426
Electronic Mail: mail@scri.sari.ac.uk
WWW: http://www.scri.sari.ac.uk/

Editor : S. Stephens
Graphics and Design : I.R. Pitkethly, S.K. Thomson
Photography : S.F. Malecki

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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'accrôitre 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 states 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 Research Council 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; and (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.

On 31st March 2003 the Institute, along with the other four Scottish Agricultural and Biological Research Institutes (SABRIs), was declassified as a non-departmental public body. 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 24th 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 16th 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, above. 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

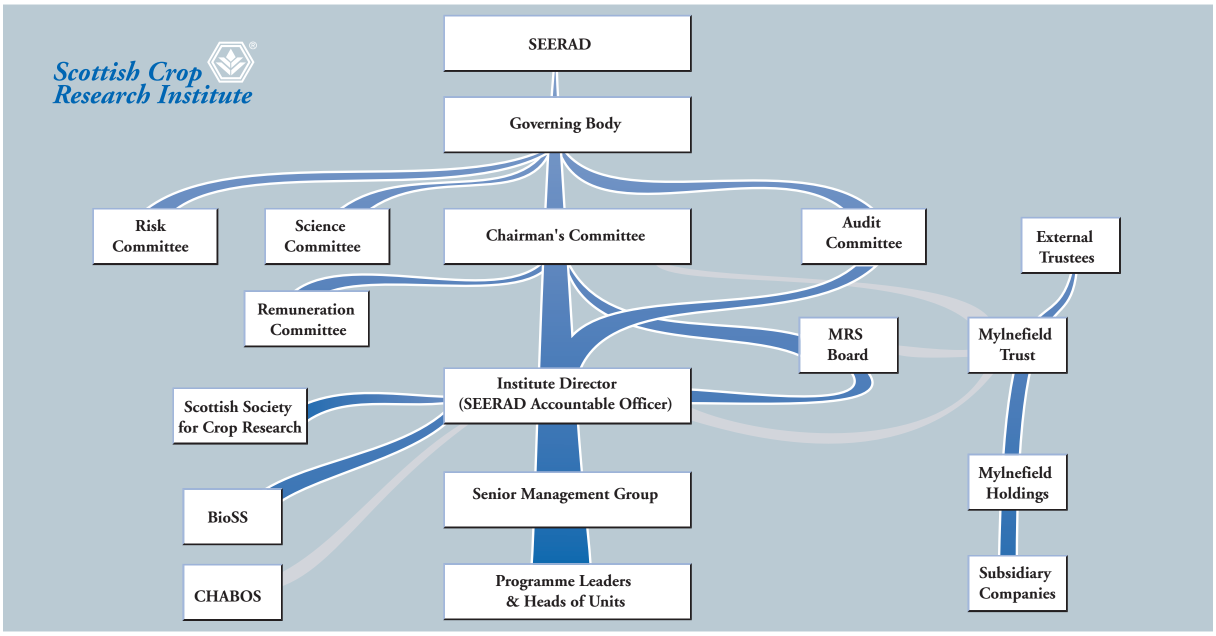


Figure 1 SCRI company and committee structure.

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 Research Organisation Assessment Exercise (ROAE, previously Visiting Group) was undertaken in May 2003 and the report was published in September 2003. In their report, ROAE members recognized the distinctive contribution SCRI makes to the UK science base and the considerable potential of the Institute. Members were impressed by the manner in which the staff had embraced the new structure and research direction introduced at SCRI in the past year. The report commented that the quality of the staff was generally high and that the quality of the total research output over the census period included much work that was clearly of international standing. The engagement with traditional end-users representing the mandate crops and the collaborative links, both nationally and internationally, with a wide range of research providers were classified as good. Areas where improvements could be made were identified and the Institute was pleased to receive the positive and constructive report.

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 biotech-

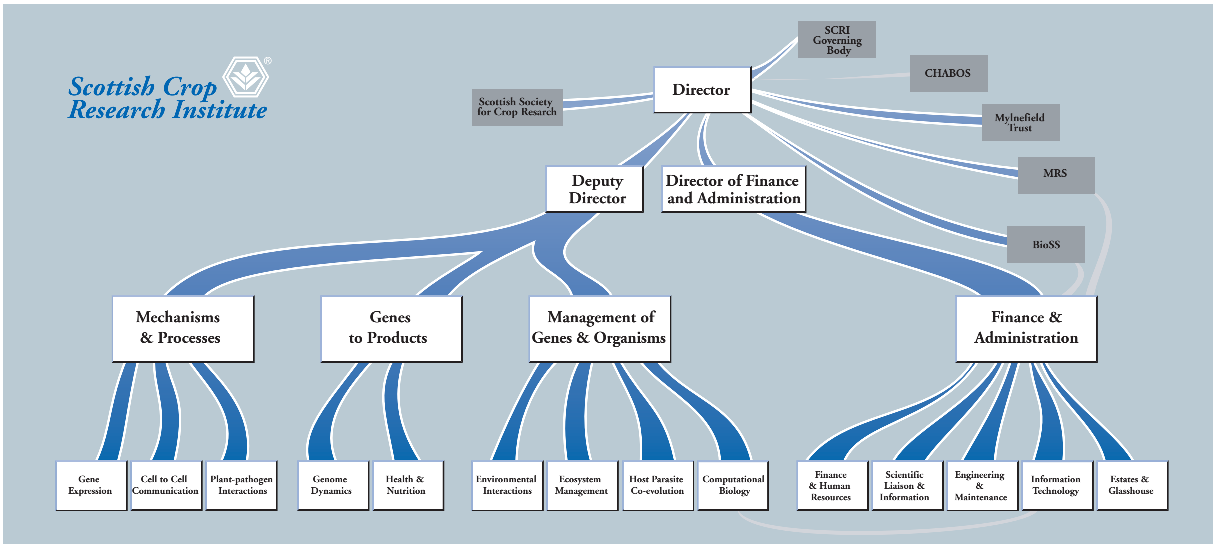


Figure 2 Institute management structure.

nology, lie at the core of our 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 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, 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 recent years, the Institute has spent over £5 million on capital equipment, upgrading of glasshouses, controlled environment, and laboratory facilities, and investment in sophisticated analytical equipment. This, along with further funding to replace another glasshouse in 2004, enhances 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 outline proposals for the possible setting up of a Science Park at its Mylnefield site. The Institute has prepared a vision and is undertaking discussions with the relevant parties. It 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 and accreditation under ISO14001 : 1996 is currently being sought. The Institute mounted an Institute-wide information and document management system (SIMS), and a comprehensive upgrade of the Institute's intranet and web site was implemented in August 2003. In addition, Mylnefield Research Services Limited (MRS) is now operating to Good Laboratory Practice Standard (an international standard) in the Lipid Unit. 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 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. BioSS was subjected to its own ROAE in May 2003 and the report was published in September 2003. In their report ROAE members congratulated BioSS on its achievements over the consensus period and in particular the scientific quality and productivity of its work.

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

This is my last Report of the Director in the SCRI Annual Report Series. It takes the form of a small selection of topics discussed in the last nine of my 19 Reports, as well as two new sections on the Consultative Group on International Agricultural Research (CGIAR) and Medicinal Plants. Throughout, the emphasis has been on global perspectives of the factors that are relevant to agricultural, biological, and environmental sciences and their associated industries. These reviews have enabled me to comment on political, social, and economic issues that are currently affecting the progress of science, engineering, and technology.

Science and Society

Apathy and Antipathy A boom was noted in science-fiction television and cinema. 'Star Trek' and its derivatives helped spawn dedicated TV channels, building on successful earlier shows, more recent series such as 'The X-Files', and the film 'Jurassic Park'. Difficulty in separating fact from fiction, scepticism over regulatory mechanisms, ignorance of scientific terminology and concepts, careful avoidance of taking up scientific careers, a total dependency on the products of science in every aspect of life and lifestyles are the collective attributes of modern adults. Antipathy to science has even permeated those areas of arts-dominated, scientifically ignorant academia concerned with 'imperialistic ideology'. Science has been described by Patrick Riley of University College London as an epistemological philosophy embracing the Humean (after David Hume, the 18th Century Edinburgh philosopher) dichotomy of rational and real knowledge. The scientific process or method involves the validation of ideas, concepts, and hypotheses about the real world by experimental comparison of the behaviour of objective reality with that predicted by conceptual models or structures. Put simply, it is a method of acquiring and using knowledge and truth, but is rarely presented as such. **1996-1997**

Political Correctness Matthew Parris, occasional commentator on the progress of the Plant Varieties Bill in the House of Commons, noted in *The Times* the emergence of a moral, ethical, or political authoritarian consensus, a development of 'political correctness', that punishes dissent or perfectly legal activities. Hysteria and emotion, stoked by the activities of tabloid media, can be seen to suppress critical analysis and silence legitimate questions. Such developments are an anathema to science. **1996-1997**

Science and *Fin de Siècle* As the new century heralds the new millennium, the historical records will bear testament to a remarkable 20th century, one of scientific, engineering, and technological achievement. At the *fin de siècle*, discoveries, inventions, and concepts relating to the biological and environmental sciences were of primary importance to the development of civilisation, offering stunning opportunities for scholarship and wealth creation, but causing concern to those unversed in, or antagonistic to, matters scientific or technological. The influence on the public and politicians of pressure groups or special interest groups opposed to scientific and technological advancement, capitalism, globalisation, multinational corporations, profitability, or even aspects of current agricultural and medical practice, was aided in Europe by compliant broadcast and publishing media. Many non-scientists sought cognitive status for the arts and humanities, accusing scientific realism of producing modern-day technocratic, bureaucratic, and relativistic tyranny; science without epistemological, ethical, and ideological awareness was claimed to worsen problems for humanity. There was a general and blatant lack of appreciation of the difference between the activity of science – the pursuit of truth and understanding – and its use, which can sometimes raise ethical issues, and sometimes discomforting truths and choices; almost invariably, though, science provides the forward momentum for improvement of the human condition. **1998-1999.**

Junk Science One particular area of concern was the growing menace of "junk" science to corporations as well as insurance and other companies in the civil justice system. This hotch-potch of speculative theories, poor statistics, and questionable honesty or independence of expert witnesses, was aided by the apparent faith of the public in the incorruptibility of its proponents. The reader is recommended to consult *Science on Trial* by M. Angell. **1998-1999.**

Mistrust In the more-developed countries (MDCs), pressure groups and special-interest groups gained greater influence over democratically elected governments, and many non-governmental organisations (NGOs) engaged directly with international governmental-based bodies. Certain pressure groups were actively opposed to the application of modern scientific advancements which they regarded in a political context as manifestations of globalisation, multinational corporations, undesirable social change, and environmental harm, all reinforced by a legally complex patent-protection system. Cynicism, suspicions, misconceptions, and prejudices about 'profits' and the rôle of the profit motive and private-sector companies in modern socio-economic systems were frequently expressed. Some of the more physically active pressure groups continued to enjoy the taxation benefits of charitable status and uncritical support by large sections of the press and television. One particular target in the UK for many anti-technology protestors, some of whom were willing to attack legally permissible field trials, was the agricultural-biotechnology sector. Playing on the naïvety of a substantial proportion of the population and political representatives to understand basic principles of conventional plant breeding, ecology, genetics, scientific research, risk-benefit analyses, and the difference between regulatory and so-called scientific failures, certain groups effectively destabilised agriculturally related European plant biotechnology. Agriculture in the UK was also influenced by the aftermath of the bovine spongiform encephalopathy (BSE) fiasco, animal-rights protestors, livestock and crop diseases, proponents of 'organic' manure-based systems, increased regulation and associated imposed costs, falling commodity prices, falling profits, raised standards and customer expectations, the growing discontinuity between scientists and the public, and entrenched attitudes to subsidies of various kinds. Mistrust of the food supply and the high levels of subsidy inputs meant that the industry increasingly assumed the mantle of a quasi-nationalised public service, more akin to urban transport, attending to the needs of a population that is becoming both divorced from, and unappreciative of, the challenges facing producers and processors, organic and conventional alike. **1999-2000.**

Scientific Integrity In previous editions of this *Annual Report*, I have described the essential characteristics of sciences and the societal need for research; both are fundamental to our appreciation of truth and progress.

Reports of misconduct over the past two decades led to several investigations at institutional level and to the intervention of national government, and even to a definition of misconduct generated by the US Office of Science and Technology Policy (see also *Responsible Science,* US National Academy of Science, 1992, and *What Price Progress?* N. Steneck*, Times Higher Education Supplement*, March 16, 2001.) Misconduct and behaviour that undermine confidence in science and scientists, and therefore compromise integrity, include falsification of results, wanton or reckless misinterpretation of results, plagiarism, bias in peer-review exercises, clogging the literature with insignificant work, failure to cite correct authorship attributions, misuse of statistics, failure to acknowledge the efforts of colleagues, lack of attention to detail, and inadequate supervision and mentoring. The setting of high standards should not be compromised whatsoever by the source of funding – public or private. Litigation will flush out misconduct or misleading work as it enters the marketplace, or becomes incorporated into public policy, so it is not in the interest of any organisation or company to tolerate bad practice. **2000-2001.**

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. **2002-2003.**

Anti-Science Strident anti-science views, even in pluralistic, multicultural societies, had the capacity to destabilise the numerically rapidly expanding political classes who were noted for the scarcity of scientists in their ranks. There was widespread confusion over such straightforward distinctions between research for curiosity, serendipitous discovery, invention, development, and commercial application. Rarely has it been possible to suppress inquiry throughout the world; the major challenge is to foster its socially acceptable application. Ridicule of scientific aspirations and vision (*e.g.* feeding the world, curing disease *etc.*) – easy because for obvious reasons there are not many irrefutable examples in younger areas of science, and hostile questioning of well-intentioned motives, also undermines scientific endeavours. In the UK, both the Office of Science and Technology in the Department of Trade and Industry, and the Scottish Executive produced strategies that were aimed at strengthening the science base. **2000-2001.**

Health Scares Repeated health scares undermined the confidence of consumers in food-safety regulations and the integrity of conventional farming. The linking by the European Union of agriculture and the environment in world trade discussions was essentially aimed at legitimising barriers to farm trade, based theoretically on one of many definitions of the precautionary principle, and was an approach largely refuted by virtually all the other members of the World Trade Organisation (WTO). **2000-2001.**

Democratic Modernity Arising from the "9/11" event were a series of precautionary actions, social developments, and a growing political and economic fragility. On October 7, military strikes led by the USA were launched against targets in Afghanistan. Hitherto-open democratic societies, politically if not intrinsically favourable to multiculturalism, questioned the accommodation of those violently opposed to secular modernity. Indeed, terrorism of all kinds was more rigorously opposed. Many in the Muslim world have yet to experience societies akin to those that arose from the enlightenment of the 17th and 18th centuries in the Christian world. George Kerevan, the journalist, pointed out that the highly pragmatic Scottish Enlightenment associated with David Hume and Adam Smith onwards, rejected tradition, superstition, and subservience to religious authority, in favour of rational scientific thought, learning, law, and property, which in turn would lead to a rational, wholesome, and civilised society capable of economic progress. Sceptical of arbitrary top-down, utopian rules, these philosophers reasoned that rules should arise from rational human conduct, tempered by social experience and education. Before that, Europe had become more or less unified through the Christian church, aided by the movement throughout the continent of scholars, communicating in Latin. Peter Watson in *The Times* (June 13, 2002) singled out the roles of three scholars: the Bolognese monk Gratian who upgraded ecclesiastical law; Robert Grosseteste (1186-1253) the inventor of the experimental method; and Thomas Aquinas (1225-1274) who made possible objective study of the natural order, and therefore the idea of the secular state. There was evidence of an increase in individuality, starting between 1050 and 1200, inside and outside the Church. Global exploration, international commercialisation, and agricultural technology improvements including horses replacing oxen and a change from the two-field to the three-field system, together began to transform Europe from a backwater compared with the Arab world and the Far East, into the condition of modernity, whereas intellectual innovation and mercantilism in China became suppressed by its bureaucratic feudalism (mandarinate) and the Arab world by its Mukhabarat. Regardless of the undoubted talents, achievements, and potential of their citizens, no Arab country *per se* is an established free democracy, to a degree they are autocracies and none has participated fully in the scientific, technological, economic, and social openness of the more-developed countries (MDCs). The reasons for this situation are numerous, and are largely attributable to a complex of both external and internal forces. Associated with this is the desperate need to resolve fairly the plight of the Palestinians. Yet modern communications, travel, education, and entertainment continue to challenge all forms of fundamentalism throughout the world, inevitably creating an endogenous backlash against imposed inflexibility and intolerance. Whether or not the 9/11 event, which led to a declared war on terrorism by President G.W. Bush, will cause the collapse of those regimes and organisations actively supporting terrorism, much changed on the global political and economic landscapes. Posterity will judge harshly those purportedly democratic and sophisticated governments that fail to address the consequences of appeasement and cowardice in the face of terrorists and terrorism, including ignoring situations which do not directly affect them on home territory. The twin counterbalancing dangers of racism and xenophobia will also have to be confronted. **2001-2002.**

Anti-Enlightenment P. Gross and N. Levitt, in *Higher Superstition : the Academic Left and its Quarrels with Science,* refer to an "anti-enlightenment", detecting the shift in contemporary non-science academic culture that now extends to a widespread suspicion of science. See also *The One Culture? A Conversation about Science* edited by J. A. Labinger and H. Collins. This trend has spawned not only a suite of social theories but stimulated radical movements that are hostile to scientific logic and sceptical of Western values and institutions. The UK is a rich source of environmental, animal-rights, anti-globalisation, anti-science, and anti-business activists. Fear of science and its products, pessimism about the future, interest in the occult, but total dependency on science, characterise a dumbing down of many societies, obsessed with entertainment of various kinds and worship of celebrity. Now, insecurity is added to this mix. Protectionist economic fortresses coupled to the threat of military force will not solve inherent problems that can be addressed only by a wider diffusion of prosperity and knowledge. **2001-2002**.

Arts The arts gained a prominent position politically and in the news media. Clinical analysis of artistic output in 1997, however, indicated worrying concerns. Stylistic plurality often incorporating technologically and interpretively puny skills; a stunning ignorance of science, engineering, and technology; transgression of the boundaries of traditional artistic media; an insatiable quest for publicity, frequently involving images calculated to disturb; integration with performance art – especially film and video with rapidly changing images appropriate only for brief attention spans; collectively made the arts less relevant, more flippant and therefore more peripheral to mainstream life than hitherto. Such apparent dynamic evolution in the arts, no matter how superficial, contrasted with the retention by the arts profession of a conventional framework of exhibitions, shows, and performances, and also with the attention they give to the reports of the critics. Many nations struggled to resolve the relationships between the overt and indirect uses of funds from the taxpayer for both the creative and evanescent not-so-creative arts, and the contribution of the subsidised arts towards wealth creation and the quality of life. The juxtaposition of the arts, design, science, technology, engineering, functionality, cultural and societal development, sustaining of cultural distinctions, literature, and challenges to conventional thinking, are complex and were rarely analysed in the depth they deserve. Certainly, the brilliant and devastating hoax article published in 1996 by two physicists, Alan Sokal and Jean Bricmont, revealed the vacuity of much of postmodernist subjectivism. Nonetheless, it seems that the arts are more likely than the sciences to provide the opportunity for the expression and recognition of unique genius as gauged by the responses of the public and politicians. **1997-1998.**

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. **2002-2003.**

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, ISBN 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. **2002-2003.**

Research Assessment in the UK Public-sector research in the financial year 1996-1997 contracted in financial terms and in the numbers of scientists and support workers employed. The contraction is set to continue. The trends and the various reviews, initiatives, and constraints are described in previous *Annual Reports*. One conspicuous feature of British science has been the virtual demise of pure and applied botany in academia, to leave but relatively few specialist university departments and individuals to link with the few Public Sector Research Institutes concerned with the plant sciences. There is a real shortage of UK-based, qualified botanists to review scientific manuscripts and grant applications, and many of the existing staff will retire within the next 10 - 15 years. In contrast to the squeeze on UK science funding, however, the rate of global scientific progress has accelerated and links with industry have become increasingly productive. Attempts have been made to measure the quality, productivity, and impact of the research funded by the public sector. Considerable emphasis seems to be placed on bibliometric data, particularly on citation analysis, which is claimed to measure the international impact of the research (*i.e.* amount of attention given to a piece of work) with a large measure of impartiality said to contrast with peer review. **1996-1997.**

UK Public-Sector Science A dispassionate review would be timely of the rôle of all those various bodies responsible for distributing public-sector resources in UK science. This would include (i) the mechanisms and impacts of their funding on shaping the national programmes; (ii) the scientific outputs and economic impacts of the work they have funded; (iii) estimates of the value-for-money of that science; (iv) the mechanisms, costs, and effects of the reviews they have carried out on the structures of the various scientific institutions they fund; (v) the full economic costs of the bureaucratic systems employed; (vi) the social impact of the work funded; (vii) their interactions with international collaborators and competitors especially in the EU and USA; (viii) possible, much simplified and cheaper mechanisms to disburse resources; (ix) future mechanisms to highlight priority areas of work and synthesise truly multidisciplinary teams; (x) future mechanisms to connect directly with the public and politicians; (xi) use of internationally robust peer-evaluation systems to review and assist in setting demanding educational and research targets, and (xii) future mechanisms to assist in changing a risk-averse culture. Until recent times, there were procedural barriers placed by central, interventionist planners and decision-makers to allow public-sector science of all disciplines to flourish in, or interact productively with, the free market (which includes industry, commerce, charities and philanthropists). The August 1999 report by J. Baker to the Minister for Science and the Financial Secretary to the Treasury *Creating Knowledge Creating Wealth. Realising the Economic Potential of Public Sector Research Establishments* is a landmark document, illustrating and justifying the pioneering rôle of MRS Ltd and the few other technology-transfer arms established in the late 1980s and early 1990s. Government and senior civil servants and policy advisors are in a difficult position. Are there too many weak or disillusioned, inflexible and/or under-supported scientists and related administrators that remain employed in Government in inappropriate types of activity merely because of the existence of a cushion provided by taxpayers? Undeniably it is an uncomfortable cushion because of the exigency of public accountability, and low reward, but it is sufficiently stable to sustain an educational, research, and bureaucratic infrastructure irrespective of diluting the effectiveness of the overall spend. In addressing any fundamental changes, with all the frictional costs involved, it would be false to adhere to the linear model of the economy being dependent on developments arising from applied science which in turn is derived from basic science. Advances in basic science depend as much on advances in technology as *vice versa,* and basic science can reach the marketplace quickly. Indeed, T. Kealy pointed out in 1996 that economic growth **is** technological development. To contribute effectively to social and economic development, science needs an interactive environment of intellectual and procedural freedom, simply because the activity of science is unpredictable, unending, exciting and visionary. Moreover, policy advice, let alone fundamental and strategic science, does not require mental corsets. **1998-1999.**

Public-Sector Science in Research Institutes Security of tenure in research institutes is weak, projects are typically of three or fewer years in duration, and the work is increasingly policy-driven. Frequent reviews of individuals, research projects, and the organisation, in parts or as a whole (periodically these are of a profound nature that can lead to closure of the organisation if they are considered to be a "quango"), and severe budgetary constraints merely compound the effects of pay agreements which are consistently below the rate of inflation. All those that sponsor research in an organisation have the right to conduct their own audits. Clearly, a fresh approach to the commissioning and reviewing of public-sector research in the UK is required. Science demands fresh blood, continually, and new ideas crossing disciplines, and efficiency of operation. Resource limitations mean that only priority areas can be funded. We must not, however, frighten off the "seed corn", as would appear to be the case with the recent depletion of numbers of first-class students seeking a career in science. A lack of expertise in key scientific areas (*e.g.* bioinformatics, plant breeding, plant pathology, plant physiology) and the dwindling numbers of high-quality UK students embarking on scientific careers caused concern in the UK Research Councils in 1997 and 1998, and some of the areas are stated in the conclusions of their SWOT analyses (strengths, weaknesses, opportunities and threats) prepared for the Office of Science and Technology. **1997-1998.**

Frascati Classification of research activity is fraught with complications, given that the research process is neither linear nor unidirectional. Applied research can generate the raison d'être for basic research-witness *e.g.* studies on photoperiodism and phytochrome. The widely applied Frascati Analysis is an Organisation for Economic Co-operation and Development (OECD) Coding and is in three major categories: oriented basic research is carried out with the expectation that it will produce a broad base of knowledge to the solution of recognised or expected practical problems or possibilities; strategic applied research is defined as applied research where the work, although directed towards practical aims, has not yet advanced to the stage where eventual applications can be clearly specified; and specific applied research is not strategic in nature and has specific and detailed processes, systems and the like as its aims. All of the UK institutes involved with the life sciences operate within these major categories, which cross-link. Development work is regarded as "near-market" and in Scotland is not funded by the Scottish Office Agriculture, Environment and Fisheries Department. There were views expressed by Professor Sir Graham Hills and others during 1997-1998 that assumptions on the linear relationship between science and innovation are flawed, and that industrial innovation stems from improved technology. Thus, more encouragement is required to switch more of the best researchers into interacting with industry, rather than adopting a condescending attitude towards matters applied and regarding blue-skies research as the acme of achievement. **1997-1998.**

Perceptions of Science in the EU Europabarometer, the EC's polling organisation, conducted a poll of 16,000 people in all 15 EU member states in 2001, noting that Europeans have become distinctly sceptical about the contributions science and technology make towards European society. More than 45% believed that too much reliance is placed on science and too little on faith, but only 36% disagreed with this view. Over 61% of people believed science and technology changed life too quickly. More than 56% thought GM food to be dangerous, over 94% wanted the right to choose whether to eat it, and 52% doubted whether scientists could help solve world hunger. The report revealed that youth in the EU is being turned off science, perhaps an unsurprising observation given the rapidly deteriorating career prospects for scientists. **2001-2002**.

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". **2002-2003.**

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. **2002-2003**.

House of Lords Primacy of place in the list of key events at the end of the millennium affecting the future of the UK was constitutional change – devolution, and fundamental change to the unelected House of Lords by eliminating, or reducing to a rump, participation of those who have hereditary rights of membership (those that remain or who are appointed, hereditary or otherwise, would apparently and anachronistically retain or acquire the privilege of titles). No clear rôle or system of election was mapped out for the House of Lords, a body that was noted hitherto for its important reports on scientific and associated matters. **1998-1999.**

Devolution Fundamental changes to the British constitution took place after the decision by the process of referendum in 1997 to establish by 2000 a Scottish Parliament and a Welsh Assembly. The Government's aim was to provide more accountable government in Scotland and Wales within the framework of the UK. The Scottish Parliament and Executive will be responsible for health; education and training; local government, social work and housing; economic development and transport; the law and home affairs; the environment; sports and the arts; research and statistics, and agriculture, fisheries and forestry. Reserved to the UK Parliament will be the constitution; UK foreign policy; UK defence and national security; the UK's fiscal macroeconomic and monetary system; common markets for UK goods and services; employment legislation; social security; and most aspects of transport safety and regulation. Relations with the EU will remain the ultimate responsibility of the UK Government but the Scottish Executive will be involved in decision-making on Europe. SCRI was one of the Scottish Public Bodies listed in Annex A of the July 1997 White Paper Scotland's Parliament (Cm 3658). These are deemed to have a remit which is concerned with matters to be devolved. Other such bodies include the other four Scottish Agricultural and Biological Research Institutes, the Royal Botanic Garden, Edinburgh, the Scottish Higher Education Funding Council, water authorities, health bodies, and advisory bodies. The SABRI remits clearly extend beyond the UK, but have a special relationship with Scotland. Any changes to the Annex A bodies will depend on ministerial decisions. The Scottish Executive will be able to alter the structure or wind-up existing bodies, and create new ones. It will also be able to alter budgets to suit its own priorities. **1997-1998.**

Devolution in the UK Devolution developed during the course of 2000. The Westminster-based UK Parliament remained the supreme law-making authority, legislating for the UK as a whole, or for any parts of it. Sovereignty resides with the Queen in Parliament. The main functions of Parliament are to pass laws, to provide the means of carrying on the work of government by imposing taxes, and to scrutinise government policy and administration. All international treaties and agreements are presented to Parliament before ratification. Contrasting with most countries, the UK constitution is not contained in a single document but has slowly evolved, and been shaped by statute, common law, and by convention. Membership of the European Union poses constraints and overrides, however. Following its election on 6 May 1999, the Scottish Parliament exerted legislative power over all devolved powers, *i.e.* matters not reserved to Westminster; primary legislation can be introduced, and the Scottish Parliament has the power to raise or lower the basic rate of income tax by three pence in the pound. The areas of responsibility cover agriculture (including agricultural R&D), economic development, education, environment, financial assistance to industry, fire services, food standards, forestry, heritage and the arts, health, housing, law, planning, police, and some aspects of transport. A busy year was experienced by the Scottish Parliament (see *Scottish Parliament Annual Report 2000 to 2001*). Thirteen bills were passed, 14 bills received Royal Assent, 71 members' business debates were held, large numbers of questions were lodged, and answered either in Chamber or in writing. The Committees of the Scottish Parliament gained a higher profile. Of relevance to this report was the work of the Rural Development (formerly Rural Affairs) Committee which devoted considerable time to the controversial Protection of Wild Mammals (Scotland) Bill, but became increasingly involved in the alarming outbreak of foot and mouth disease. Other topics covered by this committee included an inquiry into the effect of changing employment patterns in rural areas. Following a petition, GM crops were considered in a report by the Transport and the Environment Committee; this Committee also considered a petition on the environmental effects of an oilseed-crushing plant in Arbroath. Petitions from the public were firstly reviewed by the innovative Public Petitions Committee, a noteworthy democratic initiative. Cross-party groups were also active. The National Assembly for Wales was also elected in 1999 and has the power to make secondary legislation in the areas where it has been granted executive functions. The New Northern Ireland Assembly elected in 1998 was due to be formally established by legislation in 1999. It was suspended in February 2000 and resumed sitting in June 2000, and had legislative authority in the fields administered by the Northern Ireland departments. **2000-2001**.

The Dome In the UK, the Millennium Dome was built to celebrate the year 2000. Standing on the prime meridian on a reclaimed site in Greenwich, near to the Thames Barrage, the Dome was noted for its roof of tensioned fibreglass membrane covering 8 hectares and suspended from 12 masts. Such is the standing of science that early hopes that the building would house British scientific, engineering and technological achievements, and exciting new R&D projects, did not materialise, despite an expenditure on the building of over £600m derived for the most part from National Lottery funds. **1999-2000.**

Public and Private Interrelationships Legislation and regulation rapidly introduced by forceful demands in the media (*e.g.* the statistically unjustifiable ban on beef-on-the-bone, the unenforceable requirement to label genetically modified food in restaurants, excessive spending and accountability controls in the public sector etc.) essentially pander to a risk-averse society, ironically as symptoms of greater open government, and lack of trust in regulators and scientists. Simply to remove the bulk of legislation, however, let alone retard wholesale the introduction of new legislation, would expose ministers, civil, and public servants, to the vagaries of bad publicity as well as adversely affect vulnerable consumers and weaker members of society. One challenge for government regulation comes in its interface with a single dominant company or organisation in a prominent area of activity, to ensure 'public interest', however that is defined. Government must neither be the manager nor adversary of the business, if the confidence of private-sector investors is to be maintained. There is a large body of informed opinion that the establishment of a robust competition framework provides a suitable mechanism for dealing with dominant or monopolistic organisations, and where absolutely necessary, assets can be retained in the public sector but their operations can be transferred to competing private companies. This argument can be turned and extended to research provision where the public sector has until recently become a virtual monopoly addressing public-sector interests and industry-sector, but nowadays most advances in computing, telecommunications, and biotechnology are being made in the private sector, and new forms of interlinking are required. **1999-2000.**

Corporations under Siege In a revealing and acerbic analysis of pseudo-environmental and related pressure groups, Mark Neal and Christie Davies detail the tactics used to attack the business world and free enterprise in their book *The Corporation under Siege*, published by the Social Affairs Unit, London. Originally focusing on the pharmaceutical, drinks, and tobacco industries, the groups now include food, farming, forestry, mining, water and other utilities, chemicals, toys, and tampons in their sights. Aided by a mixture of uncritical, ignorant, or sympathetic journalists, and by bureaucrats who impose tough regulations even when the evidence to justify them has not been provided, there has been cynical and mendacious manipulation of public opinion; in some cases, there is evidence that the groups believe their own propaganda. Techniques used successfully to make allegations include (i) exaggeration, so that when claims are later scaled down, some of the "mud sticks"; (ii) identification of "clusters" of disease and blaming environmental causes without sound statistical analysis; (iii) mistaking coincidence for causality; (iv) claiming that small amounts of a substance are dangerous just because large amounts are; (v) ignoring real levels of risk but emphasising relative risks which sound more newsworthy; and (iv) ignoring the benefit, pleasure, or necessity of a product or process but emphasising the harm it causes. Exaggerated and irresponsible scare stories are made, damaging companies who are without recourse to appeal to claim damages. Nevertheless, there must be freedom for the public to express concern and seek explanation. **1997-1998.**

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. **2002-2003.**

"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. **2002-2003.**

Universities A growing divide was noted in higher education between the well-endowed centres of excellence, almost exclusively in the USA, and the rest. A dependence on accessing public funding, which brings in its wake bureaucratic processes and liabilities to ensure public and political accountability as well as significant extra costs and enforced uniformity, caused problems in the UK and many other countries. The scale of the problems faced by the universities related directly to their financial reserves, the quality of their management, the economic well-being of the host country, its attitude to higher education, and fostering high-profile R&D. Measures to increase efficiency included increasing class sizes, creating popular low-cost courses, better utilisation of space, tight financial management, a focus on diversifying funding sources, a switch to profitable R&D, better publicity, and policies to recruit and retain key personnel. Traditional areas of scholarship, particularly in some of the expensive underpinning sciences such as chemistry, physics, and many areas of the life sciences including botany, were under threat. In contrast, distance and e-learning were regarded positively, as they offered the promise of greatly improved efficiency and quality. Tentative steps were made towards institutional mergers in some countries. Underlying the higher education sector was a growing awareness by administrations of students and prospective students as discriminating and vocal customers. The sector also was much more international in outlook, with almost universal interconnection to the Internet *via* institutional intranets. **2000-2001.**

GATS Public education at the tertiary level (higher education provided mainly in universities and colleges of higher education) should not be assumed to be exempt from the negotiations surrounding the General Agreement on Trade in Services, part of the World Trade Organisation (WTO) agenda. Unless properly protected by robust legislation, this could result in the loss of domestic government control over Research Council funding, degree awards, and the restriction of education funding to public-sector providers. In the UK, the universities are legally regarded as essentially part of the private sector, albeit with heavy dependence on public funding and strong central controls – only the University of Buckingham is truly independent. Advice to government on universities is provided by the Higher Education Funding Councils (HEFCs) for England, Wales, and Scotland, and by the Higher Education Council in Northern Ireland. The Councils receive block grants from central government for allocation to the institutions. **2000-2001.**

Universities Many in the UK public-sector universities were unaware of the implications of the developing market in higher education arising from the General Agreement on Trade and Services (GATS), and were also unaware of the bilateral agreement between the European Commission and the USA on this topic. There is every likelihood that higher education will form part of the negotiations following the GATS talks scheduled in January 2005 unless prior agreements are put into place. Acquisition of formal accreditation roles and associated recognition, access to public funding, and greater competition for students and staff will undoubtedly open up opportunities for profit-making organisations. Presumably, non-degree-awarding research institutions such as SCRI will have a greater choice of affiliation partners, and new entrants to the market will be in a position to establish research capabilities themselves to compete for R&D funding. Debate will ensue on the definition and involvement of 'public good' and reducing or eliminating privileged access to public funding by essentially centrally controlled, formula-funded quasi-nationalised universities and further-education bodies. In 1998, 3% (equivalent to $30 billion) of the total trade in services of the 30 countries of the Organisation for Economic Co-operation and Development (OECD) was the training and education of overseas students. Over 70% of these students were trained in Australia, France, Germany, UK, and the USA, the latter accounting for 28% of the total. When the data are analysed as a proportion of total enrolments, however, overseas students accounted for 17% of the enrolment in Switzerland, 11% in the UK, and only 4% in the USA. A further problem for UK universities followed a sweeping ruling in June 2002 in the European Court of Justice that judged legislation in Germany exempting scientific research in universities from Value-Added Tax (VAT), did not comply with European Union (EU) law. It would appear that although grant income from the Higher Education Funding Councils and the Research Councils will remain exempt, research contract funding from government departments, the National Health Services, and charities (which rarely pay overhead costs) will attract VAT. **2001-2002.**

Libraries Libraries as repositories of knowledge as well as culture have been transformed by the Internet. Print materials were increasingly being scanned into digital form. Nonetheless, the costs were rising of maintenance of collections, new acquisitions, security, computer software and hardware, archiving, classification, and improving access to information. Scientific organisations, particularly in the public sector, found the costs of sustaining subscriptions to scientific journals burdensome, let alone subscribing to the stream of new journals. The numbers of on-line scientific journals increased. (See also Publishers agree on deal to link journals on the web. *Nature*, **402**, 226, 2000). **2000-2001**.

Plant diets Fruit and vegetables (*e.g.* apples; tomatoes; citrus fruits; soft fruits such as raspberries and blueberries; cruciferous vegetables, such as broccoli, cabbage, turnip and swede *etc.*), and products derived from them, were associated with disease prevention, notably of various kinds of cancer and ischaemic stroke. Uncontaminated foods derived from plants contain a wide range of compounds that may not have direct nutritional benefit, but which may affect the consumer. Those compounds may be exogenous (*e.g.* agrochemicals) or endogenous (*e.g.* potential toxins if consumed to certain levels, including alkaloids, cucurbitacins, cyanogenic glycosides, furocoumarins, glyco- and glucosinolates, hydrazine derivatives such as agaritine and gyromitrin, lathrogens, lectins, nitrates, phytoestrogens, protease inhibitors, psoralens, safrole, saponins, and vasoactive amines). Food preparation and processing can often add adventitious compounds, and offer opportunities for microbial contamination. A major target of plant breeding has been the reduction or elimination of undesirable, naturally occurring, endogenous compounds; new targets include the enhancement of factors regarded as beneficial to health. **1999-2000.**

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 World Health Organisation (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. **2002-2003.**

Herbal Products Plant scientists were intrigued by the current emphasis in the marketplace on herbal products, plant-derived dietary supplements, nutraceuticals, and functional foods. In most instances, but not all, the efficacy, and sometimes the safety of the products were not known but assumed with little evidence (see http://www.consumerlab.com) and much wishful thinking. One feature of many products was the variation in the amounts of so-called active ingredients both between apparently similar products and batches of the same product. Some dietary products were also noted to contain dangerous contaminants. Other products, however, were efficacious. More science and regulation will have to be directed to this neglected facet of oral intakes (see also *SCRI Annual Report 1999-2000* pp 83-94). **2000-2001.**

Drugs According to the 1997 World Drug Report, compiled by the UN International Drug Control Program (UNDCP), the annual turnover in drugs was estimated to be $400 billion, or about 8% of total international trade, exceeding trade in iron, steel, and automobiles. World production of coca leaf, the source of cocaine, more than doubled between 1985 and 1996, and poppy-derived opium production more than tripled. A worldwide drop in the street price of narcotics indicated that supplies were readily forthcoming. In the USA, the nation with the highest drug-consumption rate, a report in February 1997 by the Congressional General Accounting Office stated that despite a $20 billion prevention effort over a decade, supplies of cocaine and heroin continued to flood into the country at levels that were more than adequate to meet demand. This report also noted that in 1995 only about 230 of the 780 metric tonnes (mt) of cocaine produced around the world were seized by the enforcement authorities, and only about 32 of about 300 mt of heroin. Antidrug efforts by the US and certain other MDCs relied heavily on foreign governments reducing the cultivation of the source plants by eradication and crop-substitution projects, and by prosecuting the major drug traffickers. **1998-1999.**

Narcotics Plant-derived narcotics such as cocaine, heroin, and cannabis, exercised governments and international agencies such as the UN International Narcotics Control Board. Increasing well-publicised tolerance of recreational drugs and fumatories by politicians and the public, clandestine manufacture and distribution of synthetic drugs, along with poor importation and policing controls, would appear to reinforce the view that the so-called 'war on drugs' has not been as effective as originally hoped. Controls on the major growing areas in Latin America, Afghanistan, and Pakistan could potentially involve biological control agents such as species-specific plant diseases, but their use would of necessity involve exceptionally carefully planned and monitored research and development work prior to reaching international agreement on the principles of such operations. **1999-2000.**

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. **2002-2003.**

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. **2002-2003**

Food Irradiation Technological developments included the widespread application in electronic aroma-sensing instruments to detect food-product degradation, adulteration, and contamination. The number of countries that approved the use of ionising radiation (irradiation) for helping the preservation of one or more food items – typically spices, fresh fruit, and vegetables – reached 39, and 29 were using this valuable but undeservedly much-berated technology. In December 1997, the US Food and Drug Administration approved the use of ionising radiation to control disease-causing micro-organisms in meat and meat products. The procedure was declared to be safe, and to have no effect on nutritional value, taste, or appearance of fresh and frozen meat, including beef, lamb, and pork. In October 1997, President W. J. Clinton of the USA announced that the government would be undertaking new steps to ensure the safety of imported as well as domestically grown fruit and vegetables. **1998-1999.**

Urbanisation 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. **2002-2003.**

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 synthesise 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. **2002-2003.**

World Trade Organisation and Globalisation

GATT to WTO The World Trade Organisation (WTO) became effective in January 1995 after the protracted six-year Uruguay Round of negotiations by the member states of the General Agreement on Tariffs and Trade (GATT). In essence, the WTO was established to oversee the fair implementation of agreed rules governing international trade. In view of the fact that most countries, and trading blocs such as the EU, had erected complex market-distorting barriers to external trade in agricultural and horticultural produce – mainly to protect farmers, rural economic infrastructure, and to safeguard food security – the overall result has been to foster an inefficient, uncompetitive global agricultural system. In contrast, manufactured goods have been exposed to greater competitive pressures. Wars, conflicts, market collapses, unemployment, and unfair trade practices in an unstable world, however, can rapidly alter perceptions of market protection mechanisms. At this juncture, a set of five principles have been applied to international agricultural trade: (i) sanitary and phytosanitary regulations to be based on science rather than prejudice or unjustified discriminatory treatment; (ii) non-tariff barriers to trade to be converted to equivalent tariffs, with all tariffs to be reduced by at least 36% over six years; (iii) export subsidies to be cut by at least 36% and the volume of subsidised exports to be reduced by at least 21% over six years; (iv) all member nations must allow entry of duty-free agricultural imports of at least 3-5% of domestic consumption; and (v) all subsidies to domestic producers of traded products would be reduced by at least 20% over six years. **1995**

WTO Development The sovereignty of nation-states was increasingly diluted, regardless of the tendency towards fragmentation of larger nations to form smaller regional entities, by their inability to act without taking into account reactions from regional trading blocs, neighbours, and the world community. Accordingly, international law reluctantly took on a strong resemblance to constitutional law as inter-state relations become increasingly judicialised and politicised. In the area of international adjudication, the workload of the International Court of Justice increased. Two new international tribunals began operations in 1996 – the World Trade Organization's (WTO) Appelate Body was formed to hear appeals against WTO panel reports, and the inaugural meeting took place of the International Tribunal for the Law of the Sea. The UK has yet to ratify the UN Convention on the Law of the Sea which will have implications for the UK economy in that, for example, uninhabited rocks without an economy (*e.g.* Rockall) cannot be used as a basis for territorial claims to fishing and mining rights. **1996-1997.**

WTO Membership Like GATT, WTO's principal aims are to liberalise world trade through an agreed set of trade rules and market access agreements, as well as through further trade liberalisation agreements. The WTO also administers and implements a further 29 multilateral agreements in areas such as agriculture, government procurement, rules of origin, and intellectual property. By April 1997, there were 131 WTO members, and a further 28 governments being considered for membership. **1998-1999.**

Globalisation Globalisation created tensions in those anxious to sustain national sovereignty, preferences and prejudices, culture, and independence. Institutions such as the IMF, World Bank, and WTO were subject to protests, sometimes violent in nature by those resentful of their influence, and who claimed that such institutions were unresponsive to domestic civil society and tended to be secretive. Protestors demonstrated at the WTO meeting in Seattle in November 1999, the IMF and World Bank meeting in Washington in April 2000, at the World Economic Forum in Melbourne on 11 September 2000, and at the Prague Summit Meeting of the World Bank and IMF on 26 September 2000. **2000-2001.**

Globalisation To some, globalisation is an undesirable manifestation of the spread of international capitalism from the more-developed countries (MDCs), but mainly from the G-7 nations, reinforced by the International Monetary Fund (IMF), the World Bank, and the WTO. Free choice, the uptake and exploitation of technologies that improve efficiency and reliability, the free flow of information, the operation of free markets and individual choice which can develop the common good, and lightweight governance, will inexorably favour globalisation. Competition and the deployment of profit for social progress drive improvements, as do enlightened democratic processes that quell corruption and support strong legal systems. Opponents of globalisation, many of whom wished to target inequality, often presented feeble and dubious arguments which were couched in anti-business, anti-mixed-economy, anti-American, anti-technology, anti-capitalism terms and were based on the application of excessive market-distorting regulations, trade barriers, and taxation. International economic integration has become an anathema to others who wish to resist the loss of cultural diversity. Yet foreign direct investments (FDIs) affect both the providing (outward) and recipient (inward) economies, sometimes seemingly adversely in the short term, but almost without exception there are net benefits for consumers, government taxation returns, and the higher-paid workers appointed to the new enterprises. Technologies are taken up quickly. According to the *Economist* (29 September – 5 October 2001), in these early stages of globalisation most outward FDIs tend to create exports and represent net complements because affiliates of multinational companies trade with each other. Many have noted that longer-term capital contributes to economic growth in emerging markets. Whereas there is little evidence that bank loans and trade credits contribute to higher gross domestic product (GDP), for every 10 percentage point rise in the ratio of FDI stock to the economy, GDP rises by 4%. Clearly, and perhaps controversially, free trade should properly go hand-in-hand with mobility of appropriate labour. **2000-2001.**

WTO Representation Included in the criticism of the IMF and World Bank is the WTO, an organisation specifically mandated to promote international trade. Some believed erroneously that it overrode democracies through newly applied international quasi-judicial routes and was both unaccountable and unrepresentative. Yet the WTO is wholly intergovernmental, operating solely by consensus. All 142 members, soon to be joined by China after its 15-year quest, have a veto. The dispute-resolution rules were agreed unanimously, and require objective and open analyses, rather than subjective imposition. Small nations can participate actively in the struggles between the main trading blocs. With time, it is expected that the secrecy attached to trade negotiations will have to go, even though governments currently insist on the control of information. Eventually, politically tender areas of trade *viz.*: agriculture, textiles, exploitation of natural resources such as minerals and forestry, and corporate interests, look likely to be assimilated without special protection measures in all the remaining areas of trading interchange. **2000-2001.**

Agricultural Trade Trade liberalisation fostered by the WTO did not extend to matters agricultural, following the unproductive Seattle event in late 1999. Trade-distorting subsidies were criticised by the Cairns Group (Argentine, Australia, Brazil, Canada, Chile, Colombia, Fiji, Indonesia, Malaysia, New Zealand, Paraguay, Philippines, South Africa, Thailand, and Uruguay), highlighting the extraordinary protectionist measures adopted by the European Union, Japan, and South Korea, mainly on the basis that agriculture provides indirect, difficult-to-quantify benefits such as visual amenity, food security, and rural cultures. A raft of production-related subsidies, export credit and credit-guarantee programmes, peripheral subsidies, and import barriers seen in the protectionist countries is associated with complex bureaucratic processes and regressive attitudes to agriculture. Potential enlargement of the EU to include agriculturally dependent countries in Central and Eastern Europe would create enormous pressures on the EU total budget unless substantial reforms including subsidy downsizing were to take place. **2000-2001.**

WTO at Doha Despite the worsening economic situation, or perhaps because of it, new agreements were reached at the World Trade Organisation (WTO)

Conference in Doha, Qatar, in November 2001, enabling globalisation to continue and foreign direct investments (FDI) to flow. China became the 143rd member of the WTO in December, a decade and a half after first applying to join the General Agreement on Tariffs and Trade. Taiwan, a democratic country proper, was also approved for membership of the WTO, but to accede to the sensitivities of the leadership of China, it was designated as a separate customs territory together with its three offshore islands of Matsu, P'eng-hu, and Quemoy. **2001-2002.**

WTO and Agriculture 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 non-governmental organisations (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. **2002-2003.**

Approaches to Globalisation Globalisation in respect of economic integration continued notwithstanding set-backs from the 9/11 event. Internationally integrated multinational companies have largely broken down national differences; their employees usually have global interests and perspectives. Collaboration with trade unions to force through protectionist demands has been weakened, especially as the political influence of the unskilled and semi-skilled workforce has declined in relation to their proportion of the total workforce. Governments have become committed to multilateral and bilateral agreements. For Europe, the loss of large swathes of manufacturing, a steady increase in the numbers of retired people, and a willingness to purchase and use imported products, lessened resistance to globalisation in many sectors of the economy, even in the relatively resilient areas of agriculture and food. **2001-2002.**

Washington Consensus Much criticism during the year was directed at the "Washington consensus". This term introduced in 1989 by the economist J. Williamson encapsulates the promotion of trade and FDI, fiscal discipline, reduced subsidies, simplified and reformed taxation systems, liberalised financial systems, competitive exchange rates, privatisation, deregulation, and strengthened property rights. Concerns were specifically expressed at the imposition of these policies on LDCs, leading to unsustainable debts, vulnerability to the excesses of economic cycles, and political instability. Regulatory failures, corruption, and unreasonable expectations undoubtedly caused problems in the inward economies. Although the IMF and World Bank have been justifiably criticised for their prescriptive and inflexible impositions and policy blueprints, and unwillingness to permit longer periods of economic transition, they are usually only called in as a matter of last resort (as did the UK, the last MDC to do so, in the 1970s). At least, it is the case that all countries now have access to the global capital markets, and it is the politics of a country that determine its fate. **2000-2001.**

Democracy Complexed with globalisation is the rôle of democratic governments, and the need for checks and balances that prevent democracies operating insensitively as monolithic tyrannies over minorities. General taxation levels have risen in the MDCs, largely to fund social protection, defence, infrastructural, and public-good programmes. Globalisation presents, however, a challenge for governments in the raised expectations of the populace (good public services with low taxes), diminished control over the flow of capital across borders, ownership transcending national borders, international comparators that raise malcontentment, and rapid surveys of public opinions (usually influenced by the media) capable of changing the direction of policy. Biologists at least realise that all forms of diversity affecting human behaviour – cultural, ethnic, linguistic, political and economic, have their roots in differential gene expression. Governments are beginning to realise that a better-informed population tends to generate contradictory demands and expectations that in turn create political difficulties. **2000-2001.**

Cairns Group An attack on farm subsidies and agricultural trade tariffs in Europe and Japan was launched by the 15-member Cairns Group of agriculture exporters in early April 1988. The Cairns Group, named after the venue of its first meeting in 1986, includes Argentina, Australia, Brazil, Canada, Chile, Colombia, Fiji, Indonesia, Malaysia, New Zealand, Paraguay, The Philippines, South Africa, Thailand, and Uruguay. It represents 550m people and around 20% of global agricultural exports. The views of the Cairns Group in favouring trade liberalisation by lobbying against farm subsidies, export credits and trade barriers, are in accord with developments of the WTO. The EU has historically argued for exemptions in primary industries. **1998-1999.**

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. **2002-2003.**

World Food Summit 1996 The World Food Summit was held in Rome in November 1996, under the auspices of FAO to discuss global food security, at a time when 14% of the world's population suffered from chronic undernutrition, and more than 80 nations were classified as low-income food-deficient countries (LIFDCs). The world is facing a sharp decline in the supply of tillable land and fresh water *per capita*. The Summit released a 'Declaration on World Food Security' that identified the causes and actions to correct food insecurity. The goal of the anachronistically lavishly entertained summit was 'reducing the number of undernourished people to half their present level no later than 2015'. Poverty was recognised as the primary cause of food insecurity, not simply a global shortage of food. It was ironic that the majority of the world's most hungry people lived in rural areas, and more investment in agriculture was a priority, as was improved mechanisms to deal with food-aid crises.

The World Food Summit took place more than two decades after the 1974 World Food Conference, and the Overseas Development Institute noted that there are numerous achievements worthy of declaration. The proportion of undernourished people has fallen from 38% in 1969/71 to 20% in 1990/1992. A combination of new technologies and market development has stimulated world food production, such that it has outpaced population growth, although *per capita* food production has not increased in most highly indebted, low-income countries, particularly in sub-Saharan Africa. In the early 1990s, there were about 850 million people with inadequate access to food, down from 900 million in the early 1970s, even though the population of the less-developed countries (LDCs) had increased by 1.5bn over those 20 years. Famine has been largely confined since 1974 to conflict situations; drought-related crises affecting pastoralists in marginal regions have been alleviated for the most part. FAO's Global Information and Early Warning System has met the needs of those donors lacking access to the highly competent USDA intelligence network. Presently, there is no widespread sense of urgency or deepening crisis. Yet, despite all those remarkable achievements, there are far too many bodies with overlapping mandates, responsibilities, remits and missions; an institutional incoherence world-wide has led to valuable resources being spread far too thinly. Recent funding trends lean towards nations supporting high-profile, short-term special initiatives, rather than steady, longer-term investment in, say, the work of the Consultative Group on International Agricultural Research (CGIAR) network of Research Centers, or appropriate National Agricultural Research stations (NARs). **1996-1997.**

Debt Relief Political opposition from Germany and Japan and others who question the principle of debt relief delayed international efforts to relieve the debt burdens of the world's poorest countries. The UK made efforts in September 1997 to get every poor country eligible for debt relief under the Highly Indebted Poor Country Initiative (HIPC) to have made a start by 2000. Around 19 poor countries appear likely to comply with HIPC conditions of economic good behaviour in the foreseeable future. The HIPC initiative has yet to deliver debt relief to a single country. Most of the 41 countries classified as heavily indebted are in sub-Saharan Africa, including 32 countries rated as severely indebted. The most heavily indebted countries are Nigeria ($35bn), Côte d'Ivoire ($19bn) and Sudan ($18bn). Although the debt of Latin America ($650bn) is much larger than that in Africa, relief agreements and stronger economic growth have made the problem more manageable. For Africa, arrears on the debt are rising rapidly as terms of trade, commodity price turbulence and diminishing aid packages have conspired to the current situation where external debt cannot be properly serviced. To this almost insuperable problem must be added the fact that the debt owed to multilateral lenders (*e.g.* the IMF, World Bank, African Development Bank *etc.*) which do not reschedule debts – has grown also. Doubts have been raised by Graham Searjeant, the economist, as to whether the UK should surrender its aid budget to the EU or to international agencies over which the UK has little or no influence for transfer to people who cannot be readily identified. In other words, development aid becomes more akin to a tax. France and Germany, and many other countries, still operate with tied aid budgets, to the benefit of their own industries and services. **1998-1999.**

Cartegena Protocol Nominally, the UN Environment Programme (UNEP) is the world's focal point for environmental concerns, and is the first UN body to be based in the developing world – in Nairobi. It was designed to act as a repository and disseminator of information, and co-ordinator of international responses. After a period of decline in the 1990s, the Global Environment Outlook 2000 UNEP document offers a return to a central rôle, but this is now in jeopardy with proposals for the creation of a World Environment Organisation, and also with confusion over UNEP's interface with the Commission for Sustainable Development, based in New York. At the Montreal Biodiversity Conference in January 2000, the draft Cartegena Protocol on Biosafety was passed, and finalised at a meeting in Nairobi in May 2000. The protocol will take effect within 90 days after having been signed by 50 nations. In that it has the purpose to ensure public safety, maintain biodiversity, and protect and utilise organisms by providing guidelines for international trade and their use in foods, feed and processed goods, it will have a dramatic effect on biotechnology R&D, and the biotechnology industry. It is the first international treaty to incorporate the 'precautionary principle', rather than manage hazards by requiring hard scientific proof and qualification of risks; the precautionary principle insists that potential environmental risks should be dealt with even in the absence of any scientific certainty. Some regard the protocol as unworkable because it is too vague, legally and scientifically, leading to arbitrariness and vulnerability to industrial or environmental lobbyists. It is also regarded as an impedance to progress. **1999-2000.**

CGIAR The Science Council of the Consultative Group on International Agricultural Research (CGIAR) sought to define a cohesive research programme for the CGIAR system of 15 Future Harvest Centres (Table 1). Reflecting the complexity of the multinational party with dispersed centres, multiple donors, declining core funding, fragmentation of research programmes by a multiplicity of selective funding projects, a surfeit of reviews and policy analyses, a vast array of research goals, and governmental underfunding of the national agricultural research systems (NARs) with which they interact, the CGIAR needs to re-emphasise its rationale, aims and objectives, and build on its undoubted history of substantial achievements in alleviating global poverty and promoting the well-being of the world's poor.

Research priorities were originally established according to relative commodity valuations, but recognition of the fact that there are values for which it is difficult to establish market values – non-market values *e.g.* assistance to the operation of NARS, germplasm conservation, gender issues *etc.* – as well as the fact well known to the Boards and executives of research organisations that such inflexible resource appointment constrains the development of new opportunities, meant that a new approach to priority setting was timely. A further serious consideration was the fundamentally destabilising decision of the World Bank to abandon its role of donor of last resort, a measure that should galvanise Center Boards and their executives to act according to the highest standards of corporate governance and financial management.

Offering a lesson to all research institutions undergoing profound change, rather than carrying out surveys of the opinions of various stakeholders, the Science Council embarked on a process of information-gathering and broad-based consultations structured around deductive approaches, historical approaches, and inductive approaches (see *Report on CGIAR Priorities and Strategies for the Period 2005-2010: Outcomes of the Consultative Process*. Revised in August 2004, SC, Rome, Italy 240pp). As an aside it is interesting to align this analysis with that of SEERAD in developing its Research Strategy for the period 2005-2010.

From the deductive approaches, new key challenges and opportunities were identified in agriculture, as urbanisation, globalisation, private-sector involvement, sustainability, population pressures, poverty, and climate-change scenarios. Biotechnology, bioinformatics, modelling were identified – common to virtually all research institutions – as were the impacts of globalisation and bringing in new types of high-value-added agriculture coupled to vertical and horizontal integration of farmers and supply chains. Sub-Saharan Africa was seen as the greatest challenge in respect of meeting the Millennium Development Goals (MDGs). The deductive approach also considered world poverty concerns, whereby the very poorest in the world tend to function in marginal production environments in rural areas. Such environments are rarely the focus of large-scale R&D efforts, as interactions at the subsistence-level farmer bring with them factors and constraints that are often beyond the comprehension of well-meaning scientists and technologists, and the timescales for realising benefits of R&D programmes are beyond the generosity of all but a few donors. For numerous reasons, there are few instances in which a country's agricultural sector will exceed 10% of GDP, nor will agricultural exports exceed 10% of export values, factors which dissuade investments. Related to poverty concerns are world food concerns. As described in my previous *Reports of the Director*, projections made by the International Food Policy Research Institute for the predicted values of production in 2020 are worrisome. Production deficits, exchange-rate perturbations, and crucially (as a result of improving production efficiencies) exceptionally low world market prices for maize, wheat, rice, and pulses, reinforce the sharpness of the message underlying IFPRI's projections. Further support for the need to invest in agriculture comes from the Food and Agriculture Organisation of the United Nations (FAO) 2030 projections, which notes that the LDCs will become increasingly dependent upon the imports of cereals, unless yield efficiencies can be greatly improved. Consumption patterns are also changing, as are for understandable reasons, the expectation of peoples throughout the world when they benefit from modern communications.

Historical approaches examined the current and evolving CGIAR research portfolio, based on the 196 projects presented for the period 2004-2006 by the Centers, and aligned them with the priorities of partners and international organisations (*e.g.* NARS which account for over 95% of agricultural R&D spend in LDCs; the Development Banks and other R&D spon-

CIAT	Centro Internacional de Agricultura Tropical Headquarters: Apartado Aereo 67-13, Cali, Colombia www.ciat.cgiar.org
CIFOR	Center for International Forestry Research Headquarters: Jalan CIFOR, Situ Gede, Sindang barang, Bogar Barat 16680, Indonesia www.cifor.org
CIMMYT	Centro Internacional de Mejoramiento de Maiz y Trigo - International Maize and Wheat Improvement Center Headquarters: Apartado Postal 6-641, 06600 Mexico, D.F., Mexico www.cimmyt.org www.cimmyt.mx
CIP	International Potato Center Headquarters: Av. La Molina 1895, Apartado Postal 1558, Lima 12, Peru www.cipotato.org
ICARDA	International Center for Agricultural Research in the Dry Areas Headquarters: P.O. Vox 5466, Damascus Highway, Tel Hadya, Aleppo, Syrian Arab Republic www.icarda.org
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics Headquarters: Patancheru 502324, Andhra Pradesh, India www.icrisat.org
IFPRI	International Food Policy Research Institute Headquarters: 2033 K Street, NW, Washington, DC20006, USA www.ifpri.org
IITA	International Institute of Tropical Agriculture Headquarters: PMB 5320, Ibadan, Nigeria www.iita.org
ILRI	International Livestock Research Institute Headquarters: P.O. Box 30709, Nairobi, Kenya www.ilri.org
IPGRI	International Plant Genetic Resources Institute Headquarters: Viadei Tre Denari 472/a, 00057 Maccarese (Fiumicino), Italy www.ipgri.org (IPGRI/INIBAP Offices)
INIBAP	International Network for the Improvement of Banana and Plantain Base: Parc Scientifique Agropolis 11, Montpellier Cedex 5, 34397 France
IRRI	International Rice Research Institute Headquarters: DAPO Box 7777, Metro Manila, Philippines www.irri.org www.riceweb.org www.ricelib.irri.cgiar.org www.knowledgebank.irri.org
IWMI	International Water Management Institute Headquarters: P.O. Box 2075, Colombo, Sri Lanka www.cgiar.org/iwmi
WARDA	West African Rice Development Association The Africa Rice Center. Headquarters: 01 B.P. 2551, Bouaké 01, Côte d'Ivoire www.warda.org
ICRAF	World Agroforestry Centre Headquarters: United Nations Avenue, P.O. Box 30677 00100 Nairobi, Kenya www.worldagroforestrycentre.org
	WorldFish Center Headquarters: P.O. Box 500, GPO 10670 Penang, Malaysia www.worldfishcenter.org
CGIAR	CGIAR Challenge Programmes Generation c/o CIMMYT www.generationcp.org HarvestPlus c/o IFPRI www.harvestplus.org Water and Food c/o IWMI www.waterforfood.org
	CGIAR System Office CGIAR Secretariat The CGIAR, The World Bank, 1818 H Street, NW, MSN G 6-601, Washington, DC 20433, USA www.cgiar.org Science Council Secretariat SDRC, Research, Extension and Training Division, Food and Agricultural Organization of the United Nations, Viale delle Terme di Caracalla, Rome 00100, Italy Central Advisory Service on Intellectual Property IPGRI, Via Tre Denari 472/a, Maccarese (Finmincino). Rome 00057, Italy

Table 1 The Consultative Group on International Agricultural Research - The 15 'Future Harvest' Centers. the CGIAR Challenge Programmes, and administration.

sors; and private and civil society sectors – the latter influencing relationships and research resource allocations). Changing priorities are revealed by an analysis of historical budget allocations. As spending on cereals research declined, forestry, fish, and livestock spending increased proportionately. Of note is the switch of spend away from production research to environment, policy, and the conservation of biodiversity, whereas the capacity-building assistance to NARS remained at about 22% of total expenditure.

Inductive approaches (see http://www.rimisp.org/cgiar-ps2) were passed on consultations to formulate demand for incremental research, following the creation of 20 position papers written by experts on key issues. Priorities were translated into researchable activities, and then priorities were established by regions. The Science committee then provided an integrating oversight, identifying additional areas for research or new relevant opportunities. Of the 32 priority areas for additional new CGIAR research, some were regarded as strengthening producers' organisations, and others aimed at strengthening NARS. Axiomatically, adopting new areas of work could in the absence of new funding, dilute or eliminate existing projects, regardless of any efficiency savings that might be gleaned from the CGIAR system.

The Science Council proposed that the Future Harvest Centers and the CGIAR members agree to allocate 80-90% of the total CGIAR budget to ten System Priorities (Table 2).

These System Priorities remain drafts and require considerable refinement. As always, "motherhood and apple pie" aspirations are easy to generate, as are lists of worthy topics, but are incredibly difficult to translate into tangible, measurable outputs. Even with the outstanding quality of Center leadership, and outstanding scientific staff, resource constraints could lead to donor dissatisfaction in a few years hence, unless the CGIAR system fully utilises collaborative partnerships and assumes the ownership of global agricultural scholarship, and its relationship to poverty, health, nutrition and environmental management.

In an attempt to revitalise the global relevance of the CGIAR system, a 'CGIAR Renewal' initiative was launched in 1994, leading to the formation of two Partnership Committees (one for the private sector and one for the non-governmental organisations) that became operational in late 1995. Although the private-sector partnership continues, the NGO committee announced in November 2002 a unilateral freeze on its interaction with the Consultative Group System. Both committees were established on an open-ended, non-restrictive basis but were perplexed by the federalist, non-unitary decision-making CG mode, poor feedback, and highly polarised, politicised views – most notably held by certain NGOs. The private sector has been amenable to interacting with the CG system, in contrast, providing both advice on intellectual property and access to technological tools. As a result perhaps of a level of distrust over private-sector involvement and/or organisational upheaval, and despite the private-sector committee willingness to contribute positively to scientific and technological advancement, little progress has been achieved. A framework for engagement has been elaborated but there is inadequate Center responsiveness.

The NGO community is diverse, but generally suspicious of or overtly opposed to biotechnology, high-technology agricultural approaches of little or no relevance to subsistence-level farmers, intellectual-property protection, and resentful of being seemingly sidelined by the Centers. Much of its focus has been on large macro international political economy issues, and the NGO community was deeply resentful of the CGIAR system failing to support an immediate moratorium on the release of GM crops as well as continuing to conduct biotechnologically based R&D. Disengagement with the CGIAR was triggered by granting CGIAR membership to the Syngenta Foundation, a prestigious public-good-oriented charity but perceived to be a manifestation of capitalism. Examination of the breakdown in the NGO-CGIAR

1.	Conserve and characterise genetic resources
2.	Genetic improvement of specific traits
3.	Improve water management and use in agriculture
4.	Better management and use of forests and forest landscapes
5.	Better soil and land management and use
6.	Improve production and processing systems for high-value commodities
7.	Enhance resource-efficient and equitable forms of livestock sector growth
8.	Improve management and use of aquatic resources
9.	Policy and institutional innovation to reduce poverty and hunger and to enhance competitiveness of smallholders
10.	Strengthen national and regional capacities for agricultural research

Table 2 CGIAR System Priorities proposed by the CGIAR Science Council

relationship pointed out the mismatch in expectations between the NGOs and CGIAR, the absence of tangible programmes and reporting routes. Most NGOs were and remain totally opposed to any involvement of the CGIAR System with the private sector. Their hostility appears to be ideological.

A fresh appraisal of partnership arrangements was outlined in *Independent Evaluation of the Partnership Committees of the CGIAR* by K. A. Bezanson, S. Narain, and G. Prante, April 2004. They conclude on the basis of consultations that there has been too much emphasis on partnerships as ends in themselves; considerable specific detail is needed to construct a successful partnership, not least when there are major issues and problems of asymmetry of power, influence, capabilities, experience, and credibility; constituency committees are probably not the most productive way of engaging with either the private sector, or with civil-society groups; as a basic rule, generic partnership arrangements should be avoided; where institutions wish to engage in partnerships but have major differences in cultural perspectives and traditions, then front-ended investments are likely to be required over several years to sustain a functional linkage particularly during periods of tension and stakeholder disharmony; finally, evaluation criteria, standards, and timing should be integral to partnership agreements. Five types of partnership, varying in their depth of relationship, were noted: consultative, coordinative, complementary, collaborative, and the ultimate critical levels of partnership. A lengthy series of recommendations were put forward in the realisation that the CGIAR must engage with civil society groups and the private sector both to learn and to implement its own agenda for the benefit of the poor and hungry. From my perspective, civil-society groupings should not be usurped by the small group of highly vocal, media-savvy NGOs. Moreover, a cacophony of diverse, sometimes mutually incompatible voices influencing priorities could marginalise a Center-based organisation unless the Centers are brought under a robust central leadership operating to the highest standards of corporate governance. The Centers are international and are not in the ownership of the country that hosts them.

As outlined in previous editions of the *Report of the Director*, the Millennium Development Goals (MDGs) aimed to end extreme poverty by 2015, addressing low incomes, hunger, poor education, gender inequality, diseases, environmental degradation, insecurity, lack of access to safe water and sanitation. The UN Millennium Project (http://www.unmillenniumproject.org) was commissioned in 2002 by UN Secretary-General Kofi Annan as an independent advisory initiative to produce an action plan to achieve the MDGs in each low-income country ready to make the necessary commitment. From the Project has come a framework *Global Plan to Achieve the Millennium Development Goals*.

Economic development proceeds apace in China, India, and other parts of Asia. In sharp contrast, 93% of the world's extreme poor (1.089 billion) live in East Asia (271 million), South Asia (431 million), and Sub-Saharan Africa (319 million). Whereas in East Asia and South Asia, the numbers and proportions of people living in extreme poverty are declining, in Sub-Saharan Africa both the proportion and number of people living in abject poverty have risen markedly such that it is regarded as the global epicentre of the world's development crisis. Poverty levels in West Asia are increasing, and in Latin America progress in meeting the MDGs is painfully slow. In conclusion, nearly all of the afflicted regions will not be able to meet all the MDGs.

There are features that characterise extremely poor countries, some of which are intrinsically poor or more likely to have been badly governed. A summary of those features is given in Table 3

The most important steps to achieving the MDGs is a combination of commitments by both the poor countries and rich countries. Appropriately targeted aid in the short- to medium-term, will reap enormous benefits for the world. Impeding the realisation of this blatantly obvious goal is governmental reluctance in rich and poor countries alike. The donor community should help each developing country have the organisational, economic, and technical tools to implement the plans to achieve the MDGs. The rich countries should meet their widely publicised promise of 35 years ago to commit 0.7% of their Gross National Product (GNP) to official development assistance ('overseas' aid), a promise that was confirmed in the Monterrey Consensus in 2000, yet the actual level averaged just 0.23% of donor GNP. By 2003, only 5 of the 22 donor countries in the OECD Development Assistance Committee attained the promised level. Germany, Japan, and the USA have the dubious honour of giving among the smallest shares of their national income, although the USA is noted for the prominence of their outstanding charities. Some

Poverty	Present in both the urban and especially the rural poor. Sometimes concentrated in regions, in ethnic or religious groups, and may relate primarily to girls and women. Many of poor in urban areas operate in the unofficial economy. The rural poor tend to be land-constrained, dependent on rain-fed low-yield-efficient subsistence agriculture lacking access to modern technology (e.g. modern cultivars and breeds, fertilisers, pesticides, automation), and may not own their land. Frequent barriers to trade. Difficulty in meeting quality assurance standards. No access to social benefits (pensions; unemployment, disability, and child benefits; healthcare; education *etc.*) and may be hungry and thirsty. Low standards of accommodation.
Hunger and Thirst	Lack of food and potable water, access to both may involve substantial travel and sometimes dependent on the provision of aid and humanitarian support. Food quality and safety may be low. Often dependent on wood for fuel. Symptoms of malnourishment prevalent.
Disease	Slum dwellings, poverty, and hunger lead to vulnerability to pandemic diseases, especially HIV/AIDS, and the resurgence of malaria and tuberculosis. Poor or no public health provision or proper sanitation. High maternal and child mortality; low general life expectancy. Reliance on traditional and/or herbal medicine. Crops and livestock subject to catastrophic attacks of pests and diseases.
Poor Environmental Management	Depletion of natural resources, including freshwater supplies and native flora and fauna. Pollution of land, water, and atmosphere. Failure to implement national, regional, and international environmental regulations. Agricultural soils subject to erosion, salination, solarisation, desertification, and nutrient depletion. General environmental degradation. Vulnerability to flooding events. Adverse climate trends.
Poor Infrastructure	Quantity and quality of infrastructure low or absent *e.g.* roads, ports, airports, telecommunications and access to the internet, hospitals and clinics, reliable power and fuel supplies, potable water sources, sanitation, protected natural environments, storage of agricultural and horticultural produce. Poor maintenance of facilities. Demand often exceeds capacities. Rapid urbanisation and conflicts exacerbate infrastructural deficiencies. High overland transport costs.
Corruption	Lack of transparency in government and public services. Political autocracy. Low regard for human rights, health and safety, training, democratic processes. Failure to implement national and international law-policy neglect. Suppression of merit. Disconnection from robust trading arrangements. Corruption often disguised by overburdensome bureaucracy. Lack of altruistic leadership.
Low GDP *per Capita*	Few value-added products, lack of participation in the knowledge economy. Little or no foreign direct investment. Free trade constrained. Chronic lack of adequate financial assistance from MDCs, and may have poor relations with potential donor countries. Unrelieved debt burdens leading to high interest payments on loans. Little private savings, sometimes may be flight of capital. Difficulty of acquiring non-punitive credit. In balanced economies with relatively little spent on healthcare, education, and other social benefits. Economy may be damaged by previous and/or ongoing conflicts, and may in any case have limited absorptive capacity properly to manage additional resource inflows. Agriculture and unofficial transactions contribute disproportionately to the general economy.
Poor Education	No or limited access to free schooling. Low general literacy. Absence of high-grade, internationally competitive universities, colleges, and research institutions. Lack of investment in R&D, and lack of critical mass of research scientists, engineers, and technologists. Best educated and talented may leave creating a 'brain drain'. Absence of intellectual property rights, other than traditional knowledge often based on local resources; little benefit-sharing from exploited traditional knowledge and from products based on indigenous resources. Crucial demands of the LDCs are not the target of major R&D programmes (*e.g.* poverty-related diseases, herbal medicines, key crops and their pests and diseases). Lack of resources for scientists, engineers, and technologists to join networks, attend conferences, receive advanced training courses, access and participate in the relevant literature, and access expensive instrumentation and consumables.
Gender Inequality	Low educational attainment of girls and women who are regarded primarily as economic assets. Lack of female political, economic, and social representation and participation. Lack of family planning.
High Population Growth	Seen in the poorest social groups; correlates with low life expectancy and gender inequality. May exceed economic capacity of country to feed itself. Propensity to generate refugees and displaced persons.
Vulnerability to Transnational Terrorism	Terrorism often relates to poverty, hunger, poor educational attainment, and disconnection from democratic principles.
Weak Public-Sector	Lack of social benefits and protection mechanisms, poor education. Constrained public broadcasting and publishing media. Reliance on family networks or corrupt officials and politicians. Low regard for human and legal rights. Poor custodianship of cultural heritage.
Dependence on Neighbouring Nations	Reliance on and vulnerability to neighbouring countries for access to water, transport networks, foodstuffs, energy, control of environmental issues *e.g.* desertification, flooding, biodiversity protection. Neighbours may generate security problems by aiding terrorists and insurgents, or provide an uncontrolled source of refugees *i.e.* the LDC may be a victim of aggression.
Monitoring by International Organisations, MDCs, NGOs, and the Free Media	There is no excuse for the continuation of the current state of affairs. Monitoring and policy reports and recommendations should transform into action. Nation states must not be allowed to suppress their populations or components of their populations, or to inflict unwarranted aggression on others.

Table 3 Summary of Features of Countries Classified as Poor, Less-Developed, or Failing to Achieve Millennium Goal Standards. The listing is not exhaustive, and not all the features apply to most LDCs. The features also interrelate.

countries do not need substantial aid, *e.g.* China, where economic and other strategies are leading to the necessary transformations. Likewise, there are several middle-income countries where relatively small-scale assistance should be needed. For low-income and especially least-developed countries, however, the need for a scaling-up in assistance is desperate. To facilitate investments, the UN Millennium Project is scheduled to publish in early 2005 *Handbook of Best Practices to meet the MDGs.*

The MDG Project has identified 'best practices' in eight investment clusters: rural investments to promote increased food output and food availability; urban investments to promote jobs and slum improvements; health system to ensure universal access to essential health services; education system to ensure universal access to primary education; investments to overcome pervasive gender bias; cross-border infrastructure with neighbouring countries; capacities in science and technology; and public institutional capital to improve governance. Throughout the analyses on the procedures needed to accomplish the MDGs, a dynamic private sector was seen to have a central role in delivering the economic growth needed to alleviate poverty, and thus governments should have policies to provide the macroeconomic, regulatory, and legal frameworks needed to give reassurance to inward investors and encourage company start-ups and regeneration of existing businesses.

According to the 2004 Inter-Academic Council Report *Realizing the Promise and Potential of African Agriculture*, a report requested by Kofi Annan, 200 million of its 900 million inhabitants are undernourished. Widespread food insecurity exists throughout Africa. More than 60% of the undernourished live in Eastern Africa (Congo Democratic Republic and Mozambique have pronounced problems, and Angola, Cameroon, Ethiopia, Kenya, Tanzania, and Zimbabwe have malnutrition prevalence rates of between 40-50%). In West Africa, although the prevalence rate is relatively low, it still accounts for 22% of the food-impoverished poor in West and Central Africa. A contrast was drawn with Asia where the Green Revolution has made a phenomenal impact on rural poverty and the general economic climate. African farmers pursue a wide range of farming systems that vary both across and within the major agro-ecological zones of the continent – there is a lack of a dominant farming system. Rainfed agriculture dominates, and livestock play a major role. Much responsibility rests on women. There are relatively few functioning competitive markets, and some of those are distorted by aid donations and by subsidised exports from MDCs. Weathered soils of low inherent fertility dominate, and fertiliser technologies are used infrequently. Along with a severe under-investment in agricultural R&D and national infrastructures there is low labour productivity, little mechanisation, and a predominance of customary land tenure. Human-health problems (*e.g.* HIV/AIDS, malaria *etc.*) are taking an increasing toll on agricultural output. Variable economic, political, and social environments also add to the factors that imply the need for numerous 'rainbow evolutions' rather than a single Green Revolution.

Of the 17 distinct farming systems in Africa (maize-mixed, cereal/root-crop mixed, root crop, agro-pastoral millet/sorghum, highland perennial, forest-based, highland temperate mixed, pastoral, tree cropping, commercial – both small and large, coastal artisanal fishing, irrigated, rice/tree crop, sparse agriculture (arid), urban-based, highland mixed, and rainfed mixed), four were regarded as having the greatest potential to deliver the improvements needed. These are: (a) maize-mixed system, based essentially on maize, cotton, cattle, goats, poultry, and off-farm work; (b) cereal/root-crop mixed system, based primarily on maize, sorghum, millet, cassava, yams, legumes, and cattle; (c) irrigated system, based primarily on rice, cotton, vegetables, rainfed crops, cattle, and poultry; and (d) tree-crop based system, based on cocoa, coffee, oilpalm, rubber, yams, maize, and off-farm work. From these four priority farming systems arise both opportunities and problems that can be addressed by science, engineering, and technology. For near-term impact, production-ecological approach was recommended, pursuing a strategy of integrated sustainable intensification, adopting a market-led productivity improvement strategy to strengthen the competitive ability of smallholder farmers, reducing land degradation and replenishing soil fertility, recognising the potential and limitations of rainfed agriculture, exploring higher-scale integrated catchment strategies for natural-resource management, enhancing the use of mechanisation, and embracing information and communication technology at all levels. Impact in the medium term will come from embracing conventional and biotechnologically based breeding systems, as well as improving the capabilities of farmers to cope with environmental variability and climate change. In the long term, the conservation, sustainability, and equitable use of biodiversity should be promoted.

In considering that more effective institutions in Africa are required to improve agricultural productivity and food security, the Inter-Academy Council Report built on its first report *Inventing a Better Future: A Strategy for Building Worldwide Capacities in Science and Technology*, recommending a series of measures that would improve the generation and exploitation of relevant agricultural science, creating and retaining a new generation of agricultural scientists, in concert with policies to enhance the role of a vibrant market economy. To kick-start the improvement process, a series of innovative pilot programmes were recommended. **2004.**

Unstable World Africa was the most troubled continent, with wars affecting Burundi, the Democratic Republic of the Congo, and other countries in Central Africa as an aftermath of the 1994 genocide in Rwanda. A virulent, nine-year civil war in Sierra Leone was quelled by British special forces. Rebel forces disrupted the border areas of Guinea and Liberia. In December, Eritrea and Ethiopia signed a peace agreement after a prolonged series of offensive actions. Civil war persisted in parts of Asia. Afghanistan was racked by the efforts of the Taliban Islamic militia to seize overall control from an assortment of warlords. The separatist Liberation Tigers of Tamil Eelam fought with the government troops of Sri Lanka. Muslim separatist guerrillas fought the Philippine armed forces. China, an undemocratic country, blatantly threatened to use force to retake Taiwan, a wholly democratic country. The Middle East remained politically fragile, with little sign of peace between the Israelis and Palestinians. Israel terminated its occupation of southern Lebanon in May but the West Bank and Gaza witnessed scenes of violence. A suicide attack was mounted against the USS *Cole* in Aden. Enforcement of the no-fly zones in northern and southern Iraq was sustained by the UK and USA, and Turkish forces made an incursion into northern Iraq to combat Kurdish rebels. In *Deliver Us from Evil: Warlords & Peacekeepers in a World of Endless Conflict,* William Shawcross questioned the ability of the UN to solve the problems of local wars, refugees and genocide without the member nations fully implementing its Charter. **2000-2001**.

Stock Markets Investor nervousness and volatility characterised the world's stock markets in 2000. Although 'Y2K', the "millennium bug", did not materialise to jeopardise trading, a raft of factors contributed to a generally bearish sentiment later in the year. Chief amongst these were the economic outlook of the USA and the bifurcation between "old economy" and the fragile "new economy" stocks, especially businesses in the information technology (IT) sector which had been encouraged to develop disproportionately high price-earnings ratios compared with all other sectors, such that the increased weighting of IT stocks in national indices in the early part of the year led to vulnerability as investor and analyst sentiment changed later on. Other factors included rising oil prices, the threat of conflict in various parts of the Middle East, and a weak euro. As several "dot.com" or Internet-based companies collapsed – the "Internet bubble" – throughout the year, the technology, media, and telecommunications (TMT) sector suffered, leading to a sharp decline in the National Association of Securities Dealers automated quotations (Nasdaq) composite index and related technology indices in other countries. One of the features of information technology and its close association with aspects of globalisation was the internationalisation of capital markets, cross-border correlation of stock prices and international trading. A debate yet to be resolved concerns the true weighting of stocks in the various key national indices to reflect accurately and openly those that could be bought and sold, as opposed to those constrained by corporate cross-holdings, government holdings or control, or other restrictive devices. Several blue-chip companies would be adversely affected by re-weighting. Attribution of company pension liabilities was also a lively topic of discussion related to true company valuations. **2000-2001.**

Hedge Funds A hotly debated topic was the rôle of hedge funds which, in the view of some, weaken stock markets by short-selling, break down exchange-rate pacts, and target shares leading to a collapse in share prices and thereby to bear markets. Hedge-fund managers, however, pointed out their rôle in the creation of balanced markets, as well as their investment potential in recent years as an alternative to traditional equity investments. **2000-2001.**

Banking Consolidation in the banking and securities industries reshaped the global banking and financial services sectors. Procedures were put in place to eliminate local currencies in the euro zone to replace them with euro banknotes and coins by 1 January 2002. Regulatory and supervisory relationships in the banking and securities industries exercised governments of most countries, not least in the light of the formation of highly complex international groupings, and the need to reduce unnecessarily convoluted restrictive processes without undermining confidence. Loan loss provisions, classification of assets, pension provisions, risk-management processes, financial-reporting practices, and the elimination of money laundering were the main common themes. In June 2000, the report of the international Financial Action Task Force on Money Laundering identified 15 jurisdictions operating with inadequate measures, including The Bahamas, Cayman Islands, Dominica, Israel, Liechtenstein, the Philippines, and Russia. **2000-2001.**

Europe and the Common Agricultural Policy

European Monetary Union From the UK's perspective, it has been argued that to be successful, a single currency demands a single monetary policy which is part of a single economic policy. The latter would be best achieved by a single government which in a democracy should be answerable to a single electorate. For European Monetary Union (EMU), there should be criteria, conditions, and agreed processes not only for entry but also for withdrawal. Yet the introduction of the euro was decided primarily on political grounds *viz.*: to provide further impetus for European integration. The entry criteria were fudged to permit a broad entry base. At the macroeconomic level, EMU might lead to six outcomes. (i) There will be a significant distribution of wealth in the EU. Larger, internationally trading companies will benefit whereas smaller, local-trading companies will face costs and few overt benefits; prices across the EU countries will become transparent and comparable, leading to a greater degree of price arbitrage. A legal framework will be needed to ensure removal of barriers to free trade. (ii) With margins, profits, and prices under pressure, EMU will be highly anti-inflationary and possibly even deflationary in the short-to-medium term. Predatory use of tax rates by EU members would be outlawed. (iii) EMU will probably have a positive effect on economic growth in the long term, and the need for tight fiscal policy will accelerate reform of public finances; nonetheless, a deep early recession would be disastrous politically. (iv) Unemployment will remain for years well above levels considered by most economists to be necessary for price stability; malfunctioning labour markets and defective social security systems have already placed a significant tax on jobs. Radical labour market reforms are needed if monetary union is to survive. (v) With expanding transaction volumes in euro-denominated markets, the euro will become a large reserve currency to rival the dollar, making the international financial system and its institutions, such as the International Monetary Fund and the World Bank, less lop-sided towards the dollar. There is no doubt that the arrival of EMU poses a greater challenge to US economic and political orthodoxy than any previous stage of European integration, and changes in previously positive US attitudes towards EMU were reported in 1997 and early 1998. (vi) There will be extreme but not insuperable difficulty in applying a uniform monetary policy, through the transmission mechanisms (*e.g.* interest rates, exchange rates), to such a variable group of economies as currently exists in the EU. All these six predictions will be tested directly by the euro-11 countries (Austria, Belgium, Finland, France, Germany, The Irish Republic, Italy, Luxembourg, The Netherlands, Portugal, and Spain). The remaining EU countries (Denmark, Greece, Sweden, and the UK) will be involved onlookers, and features in common with the euro-11, *e.g.* the operation of the Common Agricultural Policy, could inflict EMU-induced stress in the four outsiders. **1998-1999.**

Market Flexibility Labour-market flexibility was a contentious issue in 1997. The flexibility of the US and UK labour markets was regarded by many as a major factor in improving efficiency and achieving low unemployment, whereas the highly regulated socialist practices common in most EU countries had led to high labour costs and rising unemployment, a point reinforced by the IMF in its *World Economic Outlook*. European employers were expected to bear high social costs and offer a high level of worker protection, strong disincentives to expanding staff numbers and entrepreneurial behaviour. The financial viability of social protection/security programmes caused concern worldwide. **1998-1999.**

Crisis In addition to the problems of the euro was the constitutional crisis that followed a devastating report on the European Commission, delays to competition reform as well as to the Common Agricultural Policy, gross under-achievement of EU members in peace-making operations in the Balkans, delays to enlargement of the Union, and disagreements between member states over bovine spongiform encephalopathy (BSE). A report in March 1999 by teams of former judges and auditors confirmed most of the allegations of a junior internal auditor, who had been arrogantly denounced previously by a complacent Commission. On the night that the report detailing mismanagement and nepotism, even in the area of research support, was published, J. Santer and his 19 fellow commissioners resigned en bloc. A new Commission was appointed, led by R. Prodi. In June, there was overall a poor turnout for elections to the European Parliament, with participation as low as 25% in some countries. **1999-2000.**

EU and the Euro Even though their economies were overshadowed by the world-wide economic and financial crisis, 11 of the EU countries (Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, The Netherlands, Portugal, and Spain) replaced their national currencies with a new currency, the euro, at the beginning of 1999. Foreshadowed by R. Mundell, the eminent economist who is still influential in international macroeconomics, the euro superseded national currencies and the straitjacket of relative rates when the euro was constituted. Full circulation of the currency is scheduled to take place in 2002. The launch of the euro was thought by some to be the final stage of economic and monetary union (EMU), and the IMF designated these countries as the "euro area"; other terms widely used with optional hyphenation included "eurozone" and "euroland". Monetary control moved to the 17 governing members of the European Central Bank (ECB) which now sets a common, single interest rate for all 11 countries. The internal exchange rate of the euro to the 11 national currencies was fixed irrevocably. A six-member executive board chaired by W. Duisenberg shared decision-making with the central bank governors of the 11 member countries. The stated status of the ECB was one of independence and neutrality, with price stability and low inflation as priorities. Some bankers and economists were perplexed by (i) the fact that the ECB employed only 500 staff while the national central banks employed over 60,000, (ii) the governors of the national central banks held a majority of votes in the governing council (11 votes against the ECB's six), (iii) historical mishaps of highly decentralised central banking systems *e.g.* the original Federal Reserve System of the USA, (iv) the lack of rôle as lender of last resort, (v) member states operating differing political and economic policies, and (vi) the impact of e-commerce. Thus, the ECB could be in danger of becoming an emasculated secretariat. Even the European System of Central Banks, the decentralised network comprising the ECB and national banks, would not have an explicit rôle as lender of last resort. **1999-2000.**

Agenda 2000 A major strategic document, Agenda 2000, included measures to reform the EU budget and its major spending policies, particularly the Common Agricultural Policy (CAP) and help for the economies of the less-developed member states. There was a movement away from production-related support, concomitant with the introduction of an integrated approach to rural development and agri-environmental measures. In the arable sector, a 20% cut in the cereals intervention price was proposed, alongside a single, non-crop-specific area-aid payment of 66 ecu *per* tonne for all eligible crops and set-aside areas. The Agenda 2000 package included a proposal for a new regulation on the financing of the CAP from the European Agricultural and Guarantee Fund, replacing Council Regulation (EEC) No 729/70. Denmark, Italy, Sweden and the UK (the "London Club") pressed for abolition of the 14-year-old EU milk quota system which restrains output and competitiveness. The highly regulated milk quota system was set up in 1984 in response to growing "mountains" of surplus butter and skimmed milk powder. Germany and France were hard-line opponents to reform of the quota system. The Agenda 2000 reforms were designed to allow the EU to accommodate enlargement with new member states from Central and Eastern Europe, and from the Mediterranean region. In a Heads of Government meeting in June 1998, the EU agreed that negotiations should begin with Cyprus, the Czech Republic, Estonia, Hungary, Poland, and Slovenia. Countries such as Bulgaria, Latvia, Lithuania, Romania, and Slovakia were required to carry out economic and political reforms before accession negotiations could begin, and were therefore invited into partnerships with the EU. Membership of a powerful trading bloc was attractive to isolated countries or groups of countries with weak economies, especially during the formative years of the WTO. **1999-2000.**

EU Expansion of the EU into former communist countries in Eastern Europe was retarded by the slowness in reforming the Common Agricultural Policy (CAP) and the efforts primarily of France and Germany to engage in deeper political and economic integration. Disapproval of the election in Austria of a government coalition involving the far-right Freedom

Party led to the unprecedented act by the other 14 EU partners of freezing bilateral contacts. By September, a review team concluded that the new coalition had not strayed from "European common values", in effect rescuing the EU from deadlock in its reform programme which requires unanimity. Further internal political crises in the EU were spawned by the proposal floated by the German Foreign Minister, K. Fischer, of a fully fledged European government with a written constitution, elected President, diminished national parliaments, and therefore even weaker regional assemblies. The proposal was seized on by those opposed to seemingly inexorable further political integration or who wished to unwind the current level of central control. Similarly, there was debate as to whether the EU should run its own foreign policy and defence, thereby creating disharmony with the North Atlantic Treaty Organisation (NATO) and some of the more prominent member states. Plans were drawn up in the face of opposition by the staff unions to modernise the operation of the European Commission itself, tightening up staff training, discipline, and processes to permit "whistle-blowing". The disgraceful treatment in 1999 of P. van Buitenen, the auditor, led to the resignation *en masse* of the Commission on 16 March 1999 on the grounds that lax management had allowed fraud and nepotism in the Commission's services. **2000-2001.**

CAP In the EU, agriculture continued to enjoy relatively high levels of protection from the vagaries of the marketplace. Despite a series of reforms since its inception in 1957, including the reforms of 1984, 1988, the MacSharry Reforms of 1992 and the modifications brought about by the Uruguay Round Agreement on Agriculture (1997-1999), the Common Agricultural Policy (CAP) absorbed a disproportionately large component of the EU budget. Born of a drive to increase agricultural production, provide a fair standard of living for farmers, and ensure the availability of food at reasonable prices, as well as protect small-scale, sometimes peasant-level agriculture and rural culture, the bureaucratically complex CAP distorted international trade and weakened the international competitiveness of EU agriculture. By maintaining a combination of (i) common pricing systems with associated market intervention; (ii) sustaining a dual-pricing system such that internal EU prices were kept above those in the rest of the world through direct intervention, import duties, and export refunds; and (iii) direct payments to farmers for production and output; the CAP was responsible for unfair trading, creating inducements for excess production, stultifying technological advancement, and generating anomalous actions such as 'set-aside', quotas, corruption, and overburdening paperwork. Transformation of the CAP requires unanimity of agreement between the Member States, so given the level of vested interests, it is unlikely that substantial changes will be brought about unless the deficiencies are likely to imperil the existence of the EU as a whole during enlargement or economic stress.

In 2000, France received the largest allocation (£5.7bn) of EU funds for agriculture, compared with Germany (£3.6bn), Italy (£3.2bn), UK (£2.6bn), and the Republic of Ireland (£1.1bn). The major net contributors to the EU budget were the UK, Austria, Germany, Luxembourg, The Netherlands, and Sweden, with Belgium and France as minor net contributors. Major net financial transfers were made to Greece, Portugal, Spain, and the Republic of Ireland – the so-called cohesion countries. Given the disparities in *per capita* standards of living, contributions, and receipts, the current distributions are not tenable in the medium term. **2000-2001.**

€ The euro zone is dependent on fixing interest rates on a continental scale, and reliant on the assumed authority of European institutions acting under a remit given by governments, rather than allowing its various citizens to act in a truly free market. These citizens currently live under differing political, educational, and legal systems; speak a wide variety of languages; and have differing attitudes to social and economic developments, influencing thereby the processes leading to wealth creation and the quality of life. Some of the nation states have undergone several major political upheavals and currency changes since the end of World War II in 1945. Political integration will be aided specifically by the adoption of the single currency, the euro, in turn further weakening national governments and their control of monetary policy, and lengthening the chain of contact between citizen and bureaucrat. Further constraint comes from the Stability and Growth Pact that limits governmental borrowing and budget deficits, amplifying the effects of economic downturns. With extremely limited geographic and wage flexibility of its workforce, even though a one-size-fits-all economic policy has been adopted, there is the undesirable possibility of protectionist anti-free-market policies coming to the fore, seen most clearly in agriculture, financial services, travel, and the utilities. Under the guise of 'harmonisation', anti-competitive stances could be taken as politicians try to curry favour with a voting public disillusioned with a burgeoning workforce of full-time politicians generating a flow of legislation on a massive scale. At this juncture, the European Central Bank and the relevant member states do not have large enough central budgets to offset economic shocks, a basic requirement of an optimal currency area. Regardless of intrinsic difficulties, a remarkable event took place in the euro zone in that within a space of two months at the beginning of the year, the national currencies of the 12 euro zone countries were efficiently replaced by new euro notes and coins, with minimal disruption despite the logistic and security challenges. **2001-2002.**

EU Agricultural Trade In terms of international agricultural trade, the EU was the world's leading importer of agricultural products, and the second leading exporter after the USA. Under the auspices of the WTO, the EU's position on agricultural trade liberalisation was agreed by the General Affairs Council in December 2000. A largely defensive posture was taken. Thus, there was a commitment to an overall average reduction of bound tariffs, and a minimum reduction *per* tariff line, but the EU advocated retaining the special safeguard clause to ease tariff reductions. The right to continue to use geographical indications (*i.e.* the current Protected Geographical Indication register) or designation of origin (*i.e.* the Protected Designation of Origin register, of special interest in Scotland), and a guarantee of consumer protection through the regulation of labelling (*e.g.* Traditional Speciality Guaranteed labelling) were proposed for world-wide adoption. The EU stated its willingness to negotiate further reductions in export refunds in tandem with firmer controls over other instruments used to boost exports. With regard to the domestic support of agriculture, the need for continuing reform was recognised, using the blue and green box framework of measures agreed in the Uruguay Round. More controversially, the EU wished to recognise the specific rôle of agriculture as a provider of public goods – which it is, incorporating the multifunctional rôle of agriculture in sustainable development, the protection of the environment, the sustained vitality of rural areas, and poverty alleviation. These less tangible aspects are seen externally as routes of special protection. Similarly, the EU proposed to use specific measures, including the precautionary principle, to address concerns which arose over food safety and animal welfare, again areas that might be used blatantly to distort trade, or pander to prejudice. Finally, the EU proposed measures to open up duty-free access to products from LDCs by provision of trade preferences and other forms of assistance. **2000-2001.**

CAP Reform Reform of the CAP is long overdue. Its origins lie in the original common market that reduced tariffs on industrial products from Germany in exchange for financial support for French small-scale farmers. Expansion of the system to incorporate other European countries with their own agricultural systems gave rise to bureaucratic complexities, opportunities for large-scale fraud and corruption, surpluses, waste, trade distortion to the detriment of agriculture in LDCs, the idiocies of unstructured set-aside, and a massive downturn in the wellbeing of UK agriculture. From a position of strength in 1973 when the UK joined the European Community, UK agriculture lost its competitive edge, disadvantaged by its support system relative to its European partners, the strength of the pound, and the effects of being swathed in regulations. Pressures for change are manifold: the sheer cost of CAP for the European Union, problems with the WTO and other countries, and trading blocs, the likelihood of bankruptcy for the EU if enlargement of the EU takes place without major changes to the CAP, the low profitability of agriculture and poor competitiveness of European agriculture in world markets as supply exceeds demand, and lack of political sympathy. Amidst discussion on the future direction of the CAP, notwithstanding the proposals by Franz Fischler, the EU Agriculture Commissioner, there is still the need for politicians properly to understand the essence of support mechanisms for agriculture and horticulture – the provision of low-cost, high-quality food supplies, cushioning the vagaries of the weather, pests and diseases, and volatility in world markets. This surely represents a food-access protection mechanism for poorer members of society. Trade distortion is a consequence of this underpinning support, but exceptional care is needed to lessen its impact. There is little evidence of profound thinking about the impacts of the main proposals: linkage of payments to animal welfare, health and safety, and environmental laws and regulations; increasing support for rural development, however defined; compulsory long-term set-asides on arable land; mandatory inspections; capping of direct subsidies at €300,000 *per* year. In essence, the European Commission aims to complete the process of decoupling CAP aid from farm production, a process started in 1992. If the proposals are agreed, there would be a single integrated payment for each holding, but that would be conditional on meeting certain animal-health and welfare, environmental, and food-safety standards. These conditions would operate under a common framework with basic implementation criteria enforced through an as-yet-to-be-clarified auditing system for farms receiving over €5,000 *per annum.* Starting in

2004, it is proposed that there would be "dynamic modulation" – a compulsory cumulative annual levy of 3% on direct payments. Together with capping payments, the savings will go to the "Second Pillar" rural development budget to be distributed from intensive cereal- and livestock-producing countries to poorer and more extensively farmed and mountainous countries, with the expectation of bringing about "positive environmental effects". Support will be given for assurance and certification schemes, producer groups, the farm audit scheme, and for livestock farmers using politically acceptable animal-welfare systems. Long-term set-aside (10 years) will be compulsory on arable land and will be subject to the same standards required of land in production. A 'carbon credit' of €45 *per* hectare will be given for non-food crops produced with a view to carbon-dioxide management, with a maximum guaranteed area of 1.5 million hectares. (see http://europa.eu.int/comm/agriculture/mtr/comdec_en.pdf). It is a moot point as to whether tax payers will want to pay for many environmental goods. Large-scale efficient farming units, especially those in the UK, will be penalised. Assumptions that small-scale "organic" farmers are needed in greater numbers will be tested on the rack of the market place. The UK would be a substantial loser in respect of the return from its contributions to the EU; food imports will increase. Agriculture would become even more centralised through regulation and monitoring even though direct payment support for product would decline. The overall cost of the CAP would not decline, however. Research and development to improve agricultural efficiency and product diversification would diminish, and the competitive portion of EU agriculture would be weakened.

Market manipulation comes at a high price in the medium-to-long term. The opportunities for fraud and corruption will still exist. Applicant countries rightly perceive that they will not receive the benefits of the CAP they originally understood would come their way. Nevertheless, there is resistance to change, principally from France, the Republic of Ireland, and the Mediterranean EU countries. France had 679,000 farmers in 1998, occupying 30 million hectares; its farmers and farmworkers represented 3.9% of the workforce, and agriculture accounted for 2% of French GDP. Possible advantages of the proposals would be a better matching of supply and demand – food production would pay due regard to market conditions and environmental impacts. Export subsidies would be scaled back. Encouragement to form co-operative groupings may assist in negotiation with the small number of powerful supermarket retailers, and develop confidence in investing in the future. **2001-2002.**

CAP Budget Agriculture plays a major rôle in the EU and its budget. The EC is limited to a percentage (currently 1.27%) of gross national product (GNP) it can raise from its member states, and budget revenue and expenditure must balance. Only four sources of funding are permitted: customs duties on imports from non-EU states; levies charged on agricultural imports from non-EU states; contributions based on shares of a notional Community harmonised Value-Added-Tax (VAT) base; and contributions based on shares of Community GNP, a budget-balancing item meant to cover the difference between total expenditure and the revenue from the other three sources. The "Mrs Thatcher's Rebate" initiated in 1984 (comprising 66% of the difference between the UK contributions to the budget and what it receives), represents compensation for disproportionate contributions by the UK caused by its high levels of agricultural and other imports from non-EU countries and its relatively small receipts from the CAP component of the budget.

As agricultural markets, political imperatives, and production technologies evolved, reform of the CAP was inevitable, but as in most walks of life retarded by vested interests. A particular series of reforms to the CAP took place in 1984, 1988, 1992, 1997, and 1999. Co-responsibility levels and national quotas for certain products were established in 1984. Set-aside grants to take land out of production started in 1988. The 1999 reforms were designed to reduce surpluses of cereals, beef, and milk by cutting intervention prices and compensating producers through area payments. Agenda 2000 was introduced to prepare the EU for the accession of new member states but has increased the cost of the CAP by around €1 billion *per annum* in compensation payments. The CAP is a major factor in the development of the concept of the Single Market, as codified in the EC 1985 White Paper on completing the internal market and the Single European Act which came into force in January 1993. The Act has not yet been fully implemented in respect of eliminating frontier controls and harmonisation of taxes. **2001-2002.**

Influences on EU Agriculture Overarching influences on European agriculture include not only the CAP, decisions of the WTO, global weather systems, and pests and diseases, but population and social changes. According to the 1994 UN report *The Sex and Age Distribution of the World Population*, the population of Europe will shrink from 729 million in 2000 to 677 million in 2050, whereas there will be increases in Africa (831 million to 2.14 billion), and Oceania (30,651 to 46,070). Urbanisation and suburbanisation, an increase in single-person households, increased demands for convenience foods and recreation, demands of food processors and retailers, and development of non-food agricultural and forestry outputs including industrial feedstocks, will shape the quantity and nature of supplies and various types of demand. Ownership of relevant intellectual property will become a major issue. **2001-2002.**

EU Enlargement Enlargement of the EU by accession is dependent on applicant countries being stable European democracies with free market economies. Any Accession Treaty must be approved by the Governments and parliaments of all the member states, as well as by the European Parliament in addition to the government and parliament of the applicant state. Agreements have been signed with 10 countries, Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. Those agreements commit both the EU and the applicant countries to long-term political and economic integration and thereby EU membership. So-called association agreements which initially offer EU financial assistance have been signed with Cyprus, Malta, and Turkey. Partnership and co-operation agreements that foster political and economic relations but exclude the possibility of membership have been implemented with Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Ukraine, and Uzbekistan; those agreements with Belarus and Turkmenistan are not in force. The European Economic Area (EEA) which came into effect in January 1994 from the members of the European Free Trade Area negotiated preferential access for their goods, services, labour, and capital to the European Commission Single Market. After Austria, Finland, and Sweden joined the EU in January 1995, only Iceland, Liechtenstein, and Norway remain as the non-EU EEA members, but they agreed to adopt the EU's *acquis communautaire*, apart from the sections dealing with agriculture, fisheries, coal, and steel. **2001-2002.**

EU Evolution 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 still 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 anachronistically and expensively, 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 subsidies for exports by 36% in value and reducing subsidies for 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. **2002-2003**.

EU Patents The creation of any single market area requires a common patent system. At the European Council of Lisbon, a decision was taken to introduce a "community patent" from the end of 2001. Three profound problems will need to be addressed, namely: (i) the choice of language; although English is widely accepted as a suitable technical language, cultural sensitivities mean that the ongoing enormous costs of translation are likely to continue; (ii) an intellectual property (IP) tribunal will have to be set up at the European Court of Justice in Luxembourg, and on grounds of cost it may have to set up decentralised channels, but the vested interests of many national patent lawyers will strongly oppose this aspect; and (iii) the bureaucratic processes to bring the common patent system into being are not fully integrated, and are unlikely to be changed in the short term, given the fact that the various national patent offices will have to concede power, and the essential services they provide users may suffer. Presumably, the European Patent Office in Munich will have to examine and grant new single patents. **2000-2001.**

UK Economy Keynesian economic control regulates demand either by fiscal policy (tax and public spending), or by monetary policy (interest rates). Monetarist economic policy involves setting targets for the money supply, and setting interest rates to ensure these targets are achieved, in so doing it is expected that inflation will be controlled. Modern growth theory (post-neoclassical endogenous growth theory) relates to raising the growth rate of the economy by increasing the inputs of investment and education. The UK Government appeared to adopt components of all three forms of economic control. **1998-1999.**

Environment and Climate Change

IPCC In September, the Intergovernmental Panel on Climate Change (IPCC) posted a draft of its report on the Internet (World Wide Web), concluding that the observed increase in global mean temperature of 0.3°-0.6° C was unlikely to be solely due to natural causes. In fact, the threat of global warming dominated environmental concerns, validating the prescience of the SCRI report *Global Warming: The Implications for Agriculture and Priorities for Research*, released in 1989. **1995.**

Conference of the Parties Delegates from the 166 countries that signed the 1992 UN Framework Convention on Climate Change in Rio de Janiero held the so-called "Conference of the Parties" in Berlin in March 1995. From this meeting came the Berlin Mandate which acknowledged that the target agreed at the Rio Summit of returning carbon dioxide emissions to their 1990 levels in the MDCs by the year 2000 was inadequate and that further reductions post-2000 would be necessary. A permanent secretariat was to be established in Bonn together with a negotiating group representing the major power blocs. The IPCC would remain the principal advisory body. **1995.**

Proto Kyoto Climate change remained at the forefront of environmental discussions in 1996. The second meeting of signatories to the UK Framework Convention on Climate Change met in Geneva. There was agreement to the EU and USA proposal that the OECD member states should adopt legally binding limits to emissions of 'greenhouse gases', with targets and timetables for their reduction from the turn of the millennium. Australia, Russia, and members of the Organization of the Petroleum Exporting Countries opposed the proposal, and most LDCs were concerned about the effects of these mandatory reductions on the growth of their economies. **1996-1997.**

CO_2 Emissions In July, the World Energy Council, a non-governmental interaction group promoting sustainable energy sourcing, reported that global carbon dioxide emissions from burning fossil fuels rose by 12% between 1990 and 1995, mainly from the LDCs. Emissions increased by 4% in most OECD members. Large increases of 35% and 30% were noted in the Middle East and in the Asia-Pacific region (except for Australia, Japan, and New Zealand), respectively. Levels in Africa rose by 12.5%. With the honourable exceptions of France, Germany, and the UK, all the industrialised countries (the MDCs) were unlikely to meet their target of reducing the CO_2 emissions to 1990 levels by 2000. In Central and Eastern Europe, and the former Soviet Union, 1995 emissions were over 70% above 1990 levels. **1996-1997.**

Renewables Alternative energy sourcing, like organic farming, remains a Cinderella topic. A study in 1996 by the Paris-based International Energy Agency concluded that by 2010, fossil-based fuels would still account for about 90% of total energy demand. Non-hydroelectric renewable sources (biomass, wind, wave, solar, geothermal) would account for only about 1%. The World Energy Council estimated that renewable sources could provide, subject to R&D investment, 5-8% of the world's power requirement by 2020. At the end of 1995, the signatories to the Montreal Protocol set new limits on the release of ozone-depleting substances. Industrial countries agreed to phase out methyl bromide (a fumigant and soil sterilant to control nematode pests among other uses) by 2010, and LDCs planned to stabilise its use at an average of the 1995-1998 levels by 2002. Breeding for pest and disease resistance remains a high priority internationally, commercially and environmentally, reinforcing the research strategy of SCRI. With regard to halogens, tropospheric concentrations of chlorine attributable to anthropogenic halocarbons peaked near the beginning of 1994, and by mid-1995 were decreasing at a rate of 20-30 parts *per* trillion *per annum.* Bromine concentrations, however, were still increasing. Stratospheric concentrations of chlorine and bromine were predicted to reach a maximum between 1997 and 1999, and decrease thereafter, provided that the adjusted and amended limits set by the Montreal Protocol on Substances That Deplete the Ozone Layer were not exceeded. **1996-1997.**

Fuels There was tangible evidence that low prices for fossil fuels started to weaken investments into alternative energy sources, but according to the Worldwatch Institute in Washington, USA, the capacity for generating wind power reached 7,630 MW, compared with 10MW in 1980. Shipments of photovoltaic solar cells rose 43% in 1997 to 126 MW. According to the International Energy Agency, renewable energy sources, mainly in the form of hydroelectricity and biomass (*e.g.* firewood, crop waste, charcoal, animal waste *etc.*) supplied between 15-20% of the world's energy demand. The world biomass production was calculated to be 6.9×10^{17} kcal *per* year, of which only 7% was utilised. The fact that in many countries conventional fuels were subsidised directly or indirectly, that there were insufficient incentives to convert to alternative energy sources, and that there were only small investments in research and development (R&D) in this area by both the public and private sectors, meant that technological progress and the numbers of commercially successful schemes were extremely disappointing. **1998-1999.**

Control of Atmospheric Emissions Founded on breathtaking naïvety about "stabilising" climate change and consequential ecological change by adjusting a few variables, international efforts were made to control atmospheric emissions. There was an inherent ignorance about the reality of dynamic ecosystems, of adaptation, and the need for sophisticated understanding of change. Greater numbers of weather perturbations, many difficult to predict, are anticipated as a result of changing atmospheric composition. **1998-1999.**

Abstraction of CO_2 Although energy efficiency and renewable energy are the most straightforward routes of cutting greenhouse-gas emission, other technologies based on abstracting carbon dioxide from the atmosphere may be viable in the longer term. These technologies include storage of the abstracted carbon dioxide in (i) oceans, to be trapped in sediments, hydrates, or iron-fertilised algae; (ii) terrestrial plants, especially in co-ordination with modern agronomy and forestry that reduces soil carbon oxidation and enhances carbon-trapping soil texture; (iii) geologic formations that can sequester carbon dioxide, such as oil and gas reservoirs and mines; (iv) micro-organisms that can also utilise wastes to produce valuable end-products; (v) chemical conversions to inert materials. (It was estimated that the global 1990 output of carbon dioxide could be contained in a space 10km by 10km by 150m if incorporated into magnesium carbonate); and (vi) construction cement to improve its physical qualities. The total terrestrial biomass was calculated by D. Howell and R.G. Thomas in 1996 to sequester 827 billion tonnes of carbon, the bulk by tropical rainforests (340 billion tonnes), followed by tropical seasonal forests (120), boreal forests (108), temperate deciduous vegetation (95), temperate evergreen vegetation (80), savannah (27), woodland and shrub land (22), swamp and marsh (14), and temperate grasslands (6). **1998-1999.**

Ozone, Pollution and Land Use In 1998, the ozone "hole" covering the Antarctic was the largest ever recorded, extending over an area of about twice the size of the continent (*i.e.* a 28 million sq km "hole") and extending higher above the Earth's surface than had been previously measured. A winter chill in the atmosphere leading to increased cloud formation, as opposed to increased levels of anthropogenic chlorofluorocarbons (CFCs) and halons, was given as a possible cause for the extended hole. It is on the surfaces of clouds (aerosols and ice crystals) that the CFCs and halons destroy ozone. There were alarming indications that the West Antarctic Ice Sheet, which if melted would raise sea level by 5.5m, had melted at least once in the last 1.3 million years, and that the Pine Island Glacier was retreating inland by more than 1 km a year. In the Arctic, satellite measurements showed that the southernmost edge of the pack ice near Alaska retreated hundreds of kilometres closer to the pole between 1996 and 1998.

Excess nitrogen in the biosphere caused by the overuse of nitrogen fertilizer, the emission of nitrogen oxides by vehicles and factories, livestock and human excreta, and inadequate terrestrial vegetation cover to act as nitrogen reservoirs, has become a serious problem affecting land use and coastal and estuarine waters. The potential of the natural-abundance stable-isotope facilities and expertise at SCRI to address not only the rôle of nitrogen in the biosphere but also policy matters relating to pollution has been appreciated worldwide. **1998-1999.**

Alternative Energy Major investments were made in the alternative energy sector by British Petroleum and the Royal Dutch/Shell Group. A Shell study predicted that alternative energy – principally solar, wind, and biomass but also geothermal and hydro – would provide 5% to 10% of the world's energy needs within 25 years, and could account for half of global energy consumption by the middle of the next century especially if one or more new technologies were developed. A White Paper from the European Commission in 1997 argued that member states urgently needed to draw on renewable energies to meet the Kyoto targets. In 1995, renewable energy accounted for less than 6% of total energy demand in the EU, according to Eurostat, the EU's statistical agency. There were substantial variations between countries, from Sweden's 25.4% to the UK's 0.7%. Addressing renewable energy provision has the potential to assist in the solution of the EU's Common Agricultural Policy in respect of biomass cultivation, wind- and solar-energy farms, and forestry. **1998-1999.**

Green Top 10 Plan In early June 1997, the World Bank released its Green Top 10 Plan, a list of proposed and desirable actions to address the world's most pressing environmental problems. In noting that the $800 billion *per annum* energy-related subsidies worldwide rarely benefited the poor, that global carbon dioxide emissions had increased by nearly 25% since the 1992 Rio Summit, and that 1.3 billion people were affected by polluted air, the Plan proposed two obvious actions: the phasing out of leaded petroleum spirit, and a marked reduction in the manufacture and use of chlorofluorocarbons (CFCs). More controversially, the Plan supported the market-related concept of countries trading greenhouse-gas emissions so that those countries unable to meet their targets could purchase permission to pollute from those countries whose emissions were below target. Any international programme for trading, however, would need to devise an initial allocation of emissions that would be acceptable to LDCs and MDCs, and the allowances would need to be reviewed regularly. Any scheme would face tough challenges in enforcement of regulations and shifting benchmarks. **1998-1999.**

Rio Summit Progress Later in June 1997, "Earth Summit+5", a special session of the UN General Assembly, was held in New York to review the paltry progress made in the five years since the UN Conference on Environment and Development in Rio de Janeiro (The Earth, or Rio, Summit). Pressure was placed on the USA to join the EU in setting specific targets and dates for cutting greenhouse-gas emissions which had continued to rise despite a voluntary but clearly empty agreement to reduce emissions to 1990 levels by 2000. No progress had been made in curbing the depletion of ocean fish stocks, or combating deforestation and desertification. **1998-1999.**

Kyoto Signatories to the United Nations Framework Convention on Climate Change met in Kyoto during December 1997. Proposals by the USA, including Global Warming Potential to rank greenhouse gases on their level of destructiveness, pollution credits and differentiation between MDCs and LDCs were carefully debated. Economic considerations tended to overrule environmental concerns. On 11 December 1997, a treaty – the Kyoto Protocol – was signed, committing the industrialised countries to reducing the emissions of six gases by an average of 5.2% (below 1990 levels) by 2012. Ratification started in March 1998 but there is doubt as to whether there will be full compliance by all the signatories. **1998-1999.**

EU Climate Climate change reports attracted headlines throughout the year. The EU appeared to be on track to break its own target of reducing greenhouse-gas emissions to below 1996 levels by 2000. This was attributed to the switch from coal to natural gas for generating power in the UK, the closure of inefficient factories in Germany, enhanced nuclear-power production in France, and recession-induced decline in the demand for power. Satellite evidence indicated that photosynthesis increased by an average of 10% between 1981 and 1991 in regions between latitudes 45°N and 70°N; and that higher temperatures had lengthened the growing season by 8-16 days. **1998-1999.**

Trade and Environment In *Trade, Global Policy, and the Environment*, (World Bank Discussion Paper No **402**, 1999, see also http://www.worldbank.org/) P.G. Fredriksson and associates attempted to analyse in detail the empirical links between trade and the environment, the 'pollution haven' hypothesis, and economic instruments for resolving global environmental problems. There appears to be a consensus that more open trade improves growth and economic welfare, and that increased trade and growth without appropriate environmental policies in place may have unwanted effects on the environment. Three 'effects' were considered. The 'scale' effect refers to the fact that more open trade creates greater economic activity, demanding greater inputs (e.g. raw materials, transportation, energy) and if existing technologies are deployed to increase outputs, then there is an increase in emissions along with depletion of resources. The 'composition' effect relates to changes in the relative size of the various economic sectors and sub-sectors following a reduction in trade barriers. Freer trade leads to countries specialising in sectors where they have a competitive advantage where they may have relatively abundant factors (minerals, labour *etc*.). Lax environmental regulations lead to polluting or resource-depleting industries. The 'technique' effect refers to changes in production methods that follow trade liberalisation. From a global perspective, free trade results in a more efficient use of resources. These three effects have both local and global implications.

In studies on trade, growth, and environmental and health effects, computerised general-equilibrium models were used to predict the environmental impacts of trade liberalisation. In the case of Indonesia, the damage caused by trade liberalisation was estimated to be only a fraction of the damage that normal projected economic growth and structural change would cause by the year 2020 if trade and environmental policies remained unchanged. In other studies, not surprisingly, there are widely differing trade and growth effects, and these environmental and health effects, of differing liberalisation programmes, *e.g.* linking with different trade blocs, or undergoing unilateral or complete liberalisation, select specific sectors for action, or restrict the extent of reforms. Such factors determine the scale, composition, and technique effects.

In the debate as to whether economic growth leads to improved welfare, there are four key questions. Does pollution follow a 'Kuznets' curve, an inverted-U relationship, first rising and then falling as income increases? At what income level does the turn-around occur? Do all pollutants follow the same trajectory? Is pollution reduction in LDCs due primarily to structural change, or to regulation? H. Hettige, M. Mani and D. Wheeler, in a fascinating article in the Discussion Paper, tested for a Kuznets effect by measuring the effect of income growth on three proximate determinates of pollution: the share of manufacturing in total output; the sectoral composition of manufacturing, and the intensity (*per* unit of output) of industrial pollution at the 'end-of-pipe'. Manufacturing share followed a Kuznets-type trajectory; the other two determinants did not. Sectoral composition became 'cleaner' through middle-income status and then stabilised. At the 'end-of-pipe' pollution intensity declined strongly with income. On the basis of recent trends in water pollution in the OECD, the Newly Industrialised Countries, Asian LDCs and the ex-COMECON economies, the authors concluded that industrial water emissions level off in richer economies because pollution intensity has an elastic response to income growth. Unitary elasticity, however, implies that total emissions remain constant unless other factors intervene. Industry tends to deconcentrate or relocate over time as infrastructure and prosperity spreads, but the combined existence of seriously polluted waterways in prosperous MDCs would show that the Kuznets-type hypothesis does not always hold true.

Trade liberalisation strongly impacts on agriculture, horticulture, and forestry, and in a case study in Kenya, preferential horticultural trade between Kenya and the EU had little effect on land use or Kenya's rural environment, but safeguarded marginal, survival-level producers. In the Sahel, distortions in paraffin (kerosene) and petroleum (gasoline) prices had almost no impact on the rate of woodland degradation.

Weak environmental regulations could be expected to lead to pollution-intensive industries ('pollution havens'), particularly in LDCs. Studies would indicate that factory locations and trade patterns do not appear to be strongly affected by environmental regulations, as LDC production is mainly focused on domestic markets. Sometimes, policy-makers compensate firms subjected to regulations (*e.g.* the 'Polluter Pays Principle' rarely hold true in agriculture), and stock markets, even in LDCs, are significantly affected by reports of environmental performance. The question of trade sanctions against 'free-riders' in international environmental agreements (*e.g.* the Montreal Protocol) is germane whilst there is no supranational enforcer. Political drag and regulatory chill in environmental policy-making invariably reflect on trade assessments by individual countries, but the existence of healthy democracies enforces the shouldering of global responsibilities. Environmental policies that involve taxation could well amplify existing tax distortions, just as subsidies to pollutors (such as intensive livestock agriculture and energy producers) distort the speed of addressing environmental pollution. There were also detrimental effects of weak environmental regulations on public finances, market prices, and competition. Fortunately, capital markets enforce environmental performance, where there are concerns over legal liability and damage to reputations. Not all polluters are stock-market listed, however, sobering as it is, publicly owned organisations and governments, especially in the centrally controlled economies, have been some of the worst-ever global polluters. **1999-2000.**

Carbon Output S. Dunn in *Decarbonising the Energy Economy* in *State of the World 2001,* highlighted the fact that the release of carbon atoms has been the by-product of the human harnessing of energy, from the combustion of wood, coal, lignite, oil, and through to natural gas. He noted that carbon output can be decoupled from economic growth. From the reports of the Intergovernmental Panel on Climate Change and others, it is estimated that 42 trillion tonnes of carbon are fixed in or circulate between the three main reservoirs: the atmosphere, oceans, and biosphere (*e.g.* vegetation, detritus, marine and freshwater biota, terrestrial fauna, soil and other microorganisms *etc.*). Since the start of the Industrial Revolution, more than 271 billion tonnes of carbon have been added to the atmosphere by the oxidation of fossil fuels (coal, oil, natural gas); present-day emission rates are *circa* 6.3 billion tonnes. The capacity of the main reservoirs is not known, as is a precise understanding of the social, economic, and environmental impacts of the anthropogenically added greenhouse gases (carbon dioxide, methane, nitrous oxide, and halocarbons) able to trap infra-red radiation reflected from Earth. Renewable energy sources have the potential to substitute for fossil sources, and hydrogen as a fuel of choice is a promising line of enquiry. Rarely, though, is nuclear energy regarded by reviewers as an appropriate major source for generating electricity until the issue of nuclear waste is put to rest. **2000-2001.**

Carbon Storage Carbon sequestration and storage could be achieved by technological routes such as its incorporation into inert and long-lived composite products, injecting it into oilfields which are thought by the International Energy Agency to be capable of storing 126 billion tonnes of carbon dioxide, or locking up carbon dioxide by forming stable hydrates, or reacting it with naturally occurring mineral oxides to form carbonates. The most effective approach would seem to be a reliance on photosynthesis whereby the carbon is bound into terrestrial and aquatic plants, but there are uncertainties as to the rates at which the carbon will be released by degradation processes, unless there are large-scale increases in the biomass of forestry plantations, the planting of perennial amenity and horticultural species, and iron-fertilisation of oceans to stimulate phytoplankton growth. Of course, the oceans with their ability to store carbon dioxide in the form of carbonates represents a major buffering reservoir, and perhaps the deep oceans could also store injected carbon dioxide, but again there are uncertainties as to the possibility of large-scale, uncontrolled releases, and acidification. Many environmental activists are opposed to technological fixes, and advocate the termination of burning fossil fuels. **2000-2001.**

Green Energy Renewable energy from biomass, wind, solar, and geothermal energy, and hydroelectric schemes, the so-called "green" energy, does have the capability to be operated on a smaller scale than conventional coal- and nuclear- and natural-gas powered stations. Around 70% of the world's carbon emissions in 1999 were produced by the USA (25.5%), EU (14.5%), China (13.5%), Japan (6%), Russia (4.6%), and India (4.5%). **2000-2001.**

Power Generation In Germany, Russia, and Sweden, the nuclear industry came under political pressure on safety grounds. Mainly as a result of the efforts of "green" political activists, the nuclear industry in Germany was given operating limits, and safety regulations were tightened on the transport of spent nuclear fuel. In Sweden, the closure of the Barsebäck 2 nuclear reactor was postponed as a result of the demand for electricity and the inability of the renewable energy sector to make good any shortfall. As a result of the attention given to climate change issues, there was evidence of a rethink on the future of the power-generating industries. Although the transport and custodianship of spent nuclear fuel and waste were of concern, as were catastrophic radiation leaks and terrorism, the huge potential of nuclear industry to generate carbon-dioxide-free power was becoming widely recognised. Gas- and coal-powered plants were seen to create difficulties for countries trying to meet their Kyoto obligations. Alternative energy strategies were seen to be attractive yet remained under-resourced in respect of R&D investment into the associated areas of science, engineering, and technology. Complex energy taxation arrangements were, in contrast, starting to be introduced. **2000-2001.**

Global Warming Early release of the draft of the third assessment report by the Intergovernmental Panel on Climate Change – a group acting under the auspices of the World Metereological Organisation and other sections of the UN – showed that three of the past five years had been the warmest in recent history, and dendrochronological records from the past millennium demonstrated that the abrupt twentieth century warming is unique. Human-induced (anthropogenic) warming was identified as the factor responsible for a climate warming of 0.6°C over the past century. Predictions of future "greenhouse" warming and their consequences were thought to have made little progress given the levels of uncertainty over climate models, cloud behaviour, use of fossil fuels, impacts of changing land use, solar activity, *etc.* (see Fig. 1). Studies in the melting of the Greenland ice sheet, the retreat of glaciers, worldwide, melting of the Antarctic ice sheet, and the major depletion in the average thickness of summer polar ice in recent years, were all indicative of global warming. Any threat to the oceanic conveyor belt – specifically the Gulf Stream that accounts for the temperate condition of the UK – to the global flora and fauna, and to current weather patterns justifiably caused concern and raised questions as to whether global climate change can be favourably modified or, delayed anthropogenically, or is inevitable. **2000-2001.**

Climate Change At the Sixth Conference of the Parties to the 1992 UN Convention on Climate Change held in The Hague in November 2000, there was sharp disagreement over carbon "sinks" and nuclear power. Whole-plant physiologists and soil scientists who are able to provide base-line data and determine carbon fluxes are surprisingly rare these days. Australia, Austria, Canada, Japan, New Zealand, Norway, Russia, Switzerland, Ukraine, and the USA wanted forests and agricultural land to be counted as carbon-dioxide-absorbing sinks, a stance opposed by the EU on the basis that this would obviate positive measures to meet Kyoto targets. In March 2001, President G. W. Bush of the USA stated on the

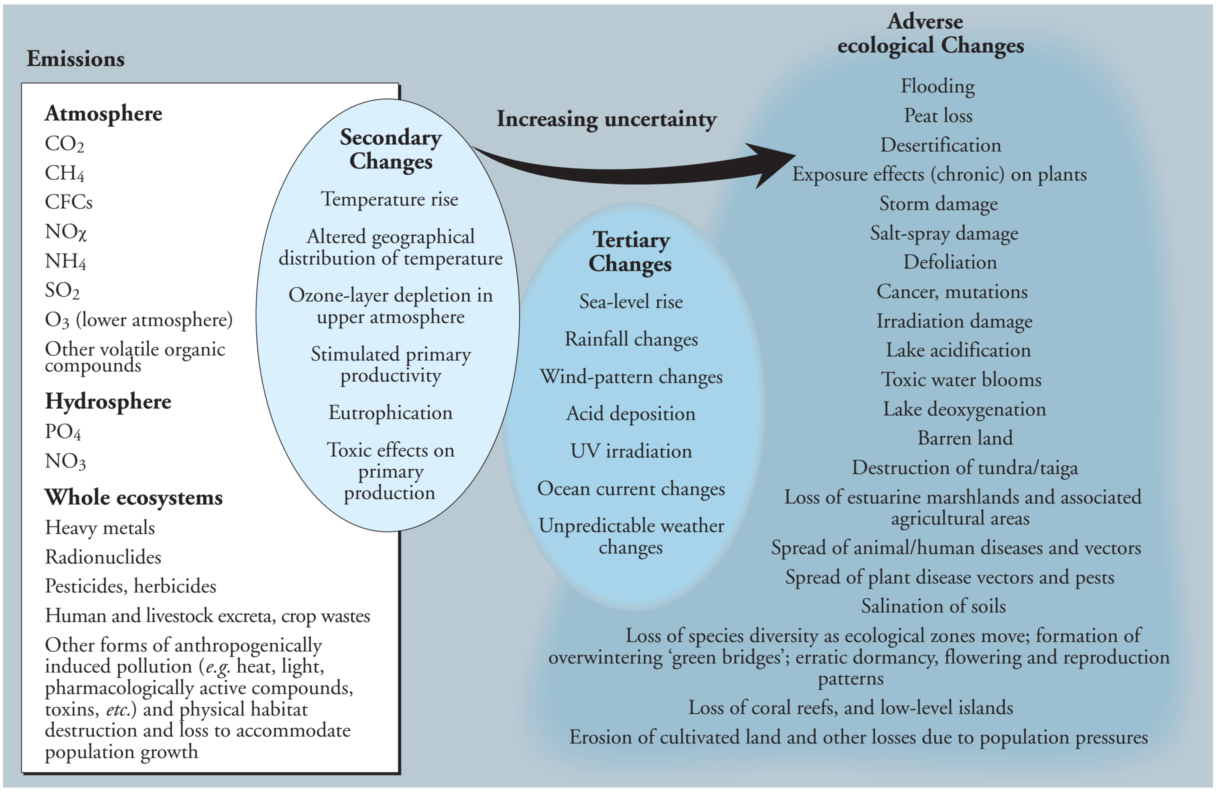


Figure 1 Principal global changes and their likely consequences.

grounds of cost that he would not accept mandatory controls on carbon-dioxide emissions. Later, in July 2001, the conference of parties met in Bonn leading to the acceptance by 178 countries to rules for meeting Kyoto targets. The USA did not accept the agreement even though there were concessions on the inclusion of carbon sinks. In November, details of the treaty were finalised: 40 MDCs would be required to reduce greenhouse-gas emissions by an average of 5% below 1990 levels by 2012. Even so, the Kyoto Protocol needed to be ratified by at least 55 countries before it could come into force. Words are usually preferred to actions in international politics. **2001-2002.**

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. **2002-2003.**

Agriculture and 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 crop 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 vegetable 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 natural 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. **2002-2003.**

Ecosystem Economic Values Few appreciate that the services of ecosystems and the natural capital stocks that produce them, are of fundamental value to humanity and to the total economic value of Earth. An international team estimated that the current economic value of 17 ecosystem renewable services (habitats, biological or system properties and processes, food, waste assimilation, erosion control *etc.*) for 16 biomes was estimated to be in the range of $16-54 trillion ($10^{12}$) per year, with an average of not less than $33 trillion per year. Global gross national product is around $18 trillion per year. **1996-1997.**

Extinctions and Restorations Habitat reconstruction (ecological restoration) to restore damaged lands and waters is a special challenge for mankind. Benign neglect, specific plantings, removal of sources of contamination, elimination of "alien" species, prevention of erosion, introduction of natural disturbances (*e.g.* controlled flooding or burning) were all attempted in 1998. Success, however, is dependent on a full appreciation of biodiversity of the flora, fauna, and soil; its measurement and conservation; and the scale of the area to be restored. According to a report in 1998 from the World Wide Fund for Nature (http://www.wwf-uk.org), 154 animal and plant species became extinct in the UK. The current rate of species extinction was calculated to be three species every two years. Since the last century, 95% of Britain's peatlands, 95% of its original grazing marshland and 50% of farm ponds have been lost. During the last 50 years, 50% of the ancient semi-natural woodland has gone, and between 1947-1985, 175,000 kilometres of hedges in England and Wales have been lost. **1998-1999.**

Gene Banks Agriculturally relevant genetic resources continued to represent a key feature of the CGIAR in concert with FAO. The CGIAR held in trust for FAO a total of around 600,000 accessions of the major food crop, forestry and agro-forestry species in its genebanks, and through the International Plant Genetic Resources Institute helped co-ordinate genetic-resources activities globally. SCRI sustains several important gene banks. The two major types of conservation were of special concern to the CGIAR, *viz. in situ* (*i.e.* maintenance of genetic diversity in its original environment where it is still a functional element of natural or agricultural ecosystems from which it acquires its particular characteristics), and *ex situ* (*i.e.* collections not in their original environment and which may be held in seed or propagule form, *in vitro* tissue culture, cryopreservation, pollen banks, seed/clonal orchards, and potentially in DNA libraries). In 1993, the Convention on Biological Diversity recognised the genetic resources occurring in a country as the sovereign property of that country, as stated in Article 15(1). It also incorporated, for the first time in international agreements, the principles of ethics and equity in both access to genetic wealth and sharing of benefits. The concepts of "biopiracy", *i.e.* not paying for source genetic material, "bioprospecting" *i.e.* seeking out new or novel genetic material and compounds derived from it, and "green imperialism" *i.e.* imposing conditions on LDCs in respect of ecological exploitation, were frequent topics of debate. **1998-1999.**

Habitat Conservation Intervention to defend the native 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. **2002-2003.**

PM10 Following on from various reports in 1995 from the WHO, the UK Expert Panel on Air Quality Standards, and the UK Committee on the Medical Effects of Air Pollutants, realigned their views on the potentially hazardous rôle of PM10, a category of airborne particles less than 10µm in size. The nature of the hazard is receiving more attention in urban areas worldwide. Planners, however, have yet to appreciate fully the atmospheric "scrubbing" capacity of various types of vegetation adjacent to roadways and factories. **1996-1997.**

Estrogenic Compounds Continued interest in various chemicals, notably the phthalates and nonyl phenols, that can mimic the physiological feminising effects of estrogens when released into the environment, drew attention to those xenobiotics which are able to modify growth and differentiation at parts *per* billion level. Extraordinary efforts and costs are required to eliminate them from the environment. **1996-1997**.

Water Pollution Removal of water from an aquifer can magnify the concentration of pollutants, enhance the inflow of saline water, cause a collapse in the aquifer structure, and affect the hydrology of the area. The major threats are pesticides, petrochemicals, chlorinated solvents, arsenic, other heavy metals, radioactive materials, nitrates, fluoride, and other salts. In the

UK, low-level but bioactive pharmaceutical pollution has become an issue. Strategies to overcome these problems include lessening the impact of agriculture so that it requires less water and agrochemicals, restricting the use and disposal of pollutants above aquifers, use of closed-loop systems, changed manufacturing systems, restricting wasteful use of water, use of end-of-pipe filters, attempts to clean or treat aquifers, use of other sources of water *e.g.* desalination of sea water, lakes, dams, *etc.*, and a search for new technological solutions. **2000-2001.**

Wastes Policies and strategies to deal with commercial, industrial, and domestic wastes have evolved from the old "the solution to pollution is dilution" approach to the current principles of (i) a waste hierarchy of reduce, reuse, recycle, and dispose; (ii) the proximity principle of disposing of waste close to its site of generation; and (iii) national self-sufficiency in dealing with wastes. The EU Landfill Directive has been brought into the public eye through its stringent targets for reducing the amount of wastes sent to landfill sites, and particularly through its planned integrated products policy which aims to internalise the environmental costs of products throughout their life-cycle through market forces by emphasising "eco-design" and incentives to promote "greener" products. Producer responsibility directives for packaging waste and the end-of-life vehicle directive adds greater responsibilities and therefore costs to producers, and consumers ultimately. Waste strategies operate for England and Wales, Scotland, and Northern Ireland. The main UK targets include (a) reduction of industrial and commercial wastes going to landfill by 85% of 1998 levels by 2005; (b) recovery of 40% of municipal waste by 2005, 45% by 2010, and 67% by 2015; (c) recycle or compost 25% of household waste by 2005, 30% by 2010, and 33% by 2015; (d) reduce biodegradable waste sent to landfill by 75% of 1995 levels by 2010, 50% by 2013, and 35% by 2020; (e) increase the proportion of waste paper in UK newspaper feedstock to 65% by 2003 and 70% by 2006; (f) reduce the amount of waste going to final disposal by 20% in 2010 and 50% by 2050; and (g) proposed re-use and recovery of 85% of the mass of end-of-use vehicles and a minimum to 80% recycling by 2006, rising to 95% re-use and recovery and 85% recycling by 2050.

Bioremediation of the atmosphere, land, and waters is patently a key technology in addressing the various tough and ambitious targets set by the EU and the UK Government. Several of the targets require entirely new approaches unless there are substantial changes in lifestyle or disenchantment of the electorate. Biotechnological advances in generating and propagating novel organisms to handle wastes, improving and maintaining planting schemes, the development of new manufacturing processes and recyclable materials, new biofuels, and other renewable energy schemes will need to be introduced soon, and will require underpinning R&D. Although sporadic small-scale public-sector investments have been made in this area, fresh and concerted effort must be made in the near future. Private-sector investments have been minimal. **2001-2002.**

Protests Ingenious and daring tactics by self-proclaimed 'eco-warriors' delayed construction of the Newbury Bypass. Extensive road construction in the UK has evoked strong protests because large swathes have been cut through areas of outstanding natural beauty, areas of specific scientific interest, and wildlife habitats. In 1997, similar protests were in evidence during construction of the extension to Manchester Airport. A feature of the various protests in recent times is the high level of public sympathy for protecting the rural environment. **1996-1997.**

Environmental Advocacy Groups According to the American Association of Fundraising Counsel Trust for Philanthropy, donations to environmental groups in the USA alone were more than $6.4 billion in 2001; globally, the income of environmental organisations was at an all-time high. The focus of attention from these advocacy groups has been business, economic growth, financial markets, profits, governments, regulators, mainstream scientists and technologists, modern agriculture, the aeroplane, and the internal combustion engine. American multinationals, fossil-fuel producers, mining companies, forestry companies, and chemical companies are particular targets of ire. Undoubtedly, the emphasis on the environment has led to improvements in the quality of water and air in many MDCs, and the areas of national parks and reserves, and conservation activities generally have all increased. In a climate of intolerance and inflexibility, it may be difficult for companies to embrace innovation to deal with the environmental costs of their actions when the pressure groups require the 'mandate, regulate, and litigate' approach rather than foster market-based environmental reforms as well. **2001-2002.**

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. **2002-2003.**

International Travel International travel and tourism has become a huge industry. Earnings were expected to exceed $450 billion in 1998 and involve at least 620 million arrivals involving about 300 million individuals. For many economies, tourism is now a prime industry, and agricultural holdings have attempted to diversify into hosting tourists and visitors to offer exposure to a rural existence, exploiting the visual amenity and local history. Nearly 70% of users of the World Wide Web were thought to have accessed a travel-related site in 1998 (a large proportion, too, accessed health-related sites). Realisation of the rôles and responsibilities of heritage sites, the rural countryside, tourist facilities and transport were beginning to exercise governments. For those sensitive to the environmental impacts of travel and tourism, there was growing awareness of the need to preserve the natural world and human cultures – leading to so-called 'ecotourism' which should be sustainable compared with the bulk of present-day travel and tourism. In theory, ecotourism could and should have benefits for travel, conservation, habitat, maintenance and employment, as well as raising the general level of environmental and cultural awareness. The establishment of bodies such as The Ecotourism Society might aid in formulating action plans and programmes to foster sustainable travel and tourism. **1998-1999.**

Crops and Cropping

Range of Food Plants The current range of home-grown and imported plants consumed in the UK is large (Table 4), although most are of minor importance and diets can be depressingly narrow. Advancements in modern retailing arrangements and marketing efforts, aided by changes in lifestyle and a massive increase in professional catering, all raise demands and expectations in the quality and type of food rather than quantity. Even though there are residual historical, ethnic, social, and economic factors that favour specific diets, growing health awareness and hedonism have become incompatible with restricted, narrow supplies and regional seasonality of produce. Blemish-free and safe produce, meat, and milk products are universal expectations of processors, retailers, and consumers alike, and dominated by the perceptions of urban dwellers.

Man is the only animal to cook food, a process which widens the range of species consumed. Compared with fresh plant food, cooking modifies the appearance, taste, and texture, frequently removing anti-nutritional, toxic, and other components, and affecting cell integrity. Vitamins and micronutrients may be lost too, but more cellular material is made accessible to gut secretions. Only in recent times has attention been given to antioxidants and free-radical scavengers in the diet, to dietary fibre, to personal bioremediation possibilities by dietary intake, and to the psychology of food choice. A future challenge is the problem of pro-

1. *Poaceae (Gramineae)*

The cereals	- barley, oat, rice, rye, wheat
Coarse grains	- maize, sorghum
Forage grasses	
Sugar cane	

Grass fruits (caryopses or grain) are the largest single source of carbohydrate on earth.

2. *Leguminosae*

Forage legumes	
The pulses	- adzuki, blackgram, broadbean, chickpea, cowpea, haricot, horsegram, jack, kidney, lablab, lentils, lima, mat, mung, pea, pigeonpea, soya, string- and snapbean, sword, vetches, yambean

Proteinaceous, sometimes contain toxins, allergens or haemagglutinins. Also produce oils.

3. *Solanaceae*

Aubergine	Potato
Capsicum	Tomato

4. *Cruciferae*

Broccoli	Kohl-rabi
Brussels sprout	Mustard and Cress
Cabbage	Oilseed rape
Cauliflower	Radish
Chard	Swede
Chinese leaves	Turnip
Kale	

Proteins, oils and carbohydrates. The most important group of green vegetables.

5. *Chenopodiaceae*

Beet	- fodder, garden, spinach, sugar
Mangold	
Spinach	
Swiss chard	

6. *Liliaceae*

Chives	Onion
Garlic	Onion - Egyptian, spring, Welsh
Leek	Rakkyo

7. *Rosaceae*

Soft fruit	- blackberry, currant (black/red/white), gooseberry, hybrid berries, raspberry, strawberry
Stone fruit	- almond, apricot, cherry, damson, greengage, nectarine, peach, plum
Top fruit	- apple, medlar, pear, quince

8. *Cucurbitaceae*

Courgette/Zucchini	Melon
Cucumber	Melon (water)
Gourd	Pumpkin
Marrow	Squash

9. *Umbelliferae*

Carrot	Parsley
Celeriac	Parsnip
Celery	

10. Major imported families

Anacardiaceae	- mango, cashew
Araceae	- cocoyams, dasheen, yautia, taro
Bromeliaceae	- pineapple
Convolvulaceae	- sweetpotato
Euphorbiaceae	- cassava
Musaceae	- banana, plantain
Palmae	- date palm, sago palm, oil palm, betel nut
Rubiaceae	- coffee
Rutaceae	- citron, grapefruit, lemon, lime, orange, pummelo, tangerine
Sterculiaceae	- cocoa, cola
Theaceae	- tea

11. Miscellaneous horticultural plants

Artichoke	Macadamia
Avocado	Mulberry
Blueberry & cranberry	Okra
Breadfruit	Papaya
Chestnut	Passionfruit
Endive	Pecan
Fig	Pistachio
Grape	Pomegranate
Guava	Rhubarb
Hazelnut	Tamarind
Lettuce	Walnut

Also includes flavourings, fumatories, herbs and spices and masticatories.

Table 4 Range of food plants consumed in the UK.

cessing sewage resulting from the modern diet and medication. **1995.**

Crop Production Economists recognise that neither import substitution nor a trade deficit justify unfettered agricultural and horticultural production in the present-day international trading environment, even if the land resource and labour were available. Economic justification is a prerequisite. **1995.**

Food Crops Plant breeding is central to the success and efficiency of agriculture, horticulture, and forestry. In a succinct and timely analysis of the rationale for exploiting novel germplasm in plant breeding programmes, J.S. Heslop-Harrison (Exploiting novel germplasm. *Aust. J. Agric. Res.,* 2002, **53**, 873-879), pointed out that of the 250,000 species of flowering plants, 12 species provide 75% of the food eaten, and only four species account for half of all the food eaten (Table 5). All the listed crops are capable of being biotechnologically modified. **2001-2002.**

Roadmap Agriculture is the single most important activity for human existence. The efficient production of crops and livestock for food supplies and industrial feedstocks has released humanity from the hunter-gatherer treadmill. Scientific, engineering, and technological advances have removed the drudgery. World

Crop	2001 production (Mt)
Sugar cane	1254
Maize	605
Rice	593
Wheat	579
Potato	308
Sugar beet	234
Cassava	179
Soybean	177
Barley	139
Sweet potato	136
Oil palm fruit	119
Tomato	100
Banana & plantain	98
Watermelon	77
Grape	62
Orange	61
Apple	60
Sorghum	58
Cabbage	55
Coconut	51
Onion	47
Yam	39
Rapeseed	36
Groundnut	35
Cucumber & gherkin	31
Millet	29
Oats	27

Table 5 The world's major food crops for human consumption ranked by production (from FAO Statistical Database, http://apps.fao.org, 2002). Banana and plantain have been combined, and the pooled category 'Vegetables Fresh not elswhere specified' has been omitted (between positions 6 and 7).

food production has quadrupled since 1950, using just 1% more cultivated land; the world's population has grown and has the capability to expand further; less than one in ten people do not have enough to eat whereas 50 years ago, that figure was one in four. Civilisation has been allowed to proceed. Food-supply security is no longer a political priority in the UK and many other countries. The global economy, human health, and societal development have been, for the most part, positively influenced by agriculture, but there are debates about the environmental costs of certain types of agriculture, although large portions of the terrestrial environment have been shaped by mankind. Drawing on *A Science Roadmap for Agriculture* (cited as *Task Force on Building a Science Roadmap for Agriculture*, National Association of State Universities and Land-Grant Colleges, Experiment Station Committee on Organization and Policy, "A Science Roadmap for the Future". November 2001 (http://www.nasulgc.org/comm_food.htm)) there are huge challenges in defining the needs of agriculture and the future direction of the various strands of agriculturally relevant science. The Science Roadmap was designed for the USA, but it has resonance for the EU and the UK. It followed a conceptual framework of needs to (a) be competitive in a global economy; (b) add value in future harvests; (c) adjust agriculture to a changing climate; (d) be good stewards of the environment and natural resources; (e) make agricultural enterprises profitable; (f) make families and communities strong; and (g) modify foods for improved health and safety. From these needs arose seven challenges which align closely with European agricultural perspectives, addressing common points in the background information and rationale, the consequences of failing to address these needs, the specific objectives of the research programmes, and potential impacts of the research. These challenges should take precedence over the recommendations of the recent Curry Commission report on the Future of Farming and Food, not least given the extensive and expert analyses devoted to the US study. **2001-2002.**

Non-Food Crops My previous reviews have concentrated on food-related matters, but non-food primary products are of critical importance to humanity, and will increasingly be the focus of biotechnology. The actual and potential benefits of plant-derived non-food products are based not only on their intrinsic utility but also on their renewability or sustainability, especially compared with oil-based products. With few exceptions, they can be biodegradable and are not considered toxic. These desirable characteristics were emphasised by the House of Lords Select Committee on Science and Technology in their report of December 1999 into non-food crops, and by M. Askew in the IENICA project. Botanists are well aware of the extraordinary number of uses of plant-derived products (Table 6) as well as the actual and potential higher-plant species available for exploitation. Application of modern sciences can and will dramatically shift the balance of industry towards utilising the full panoply of benefits of renewable resources, and agricultural and forestry biotechnology will inevitably start to play a major rôle in optimising the sourcing of customised plant products. **1999-2000.**

Non-Food Crops Non-food uses of crops would seem to be an attractive area of agricultural activity, creating new types of investment, income, and employment

Carbohydrates
- Fabric stiffeners
- Detergents
- Fermentation substrates
- Cosmetics and toiletries
- Paint additives
- Pharmaceuticals and nutraceuticals
- Water-purification treatments

Oils, fats and waxes
- Biodegradable polymers, plastics, and plastic foams
- Biosolvents
- Fuels (*e.g.* biodiesel)
- Linoleum
- Lubricants and anti-binding treatments
- Paints and surface coatings (*e.g.* varnishes, alkyl resins)
- Printing inks
- Surfactants, soaps, and detergents
- Emulsifiers
- Oilcloth
- Rubber additives
- Plasticisers
- Hydraulic fluids
- Non-drying, semi-drying, and drying oils
- Polishes
- Cosmetics

Proteins
- Adhesives and glues
- Controlled release of pharmaceuticals and other chemicals
- Cosmetics
- Packaging
- Pharmaceuticals and nutraceuticals
- Plant-protection and pest-control agents

Fibres
- Composites, including laminates, particle, and ply boarding
- Geotextiles
- Growth media
- Insulation, fillings and stuffings
- Ion-exchange
- Matting and non-woven products for filtration
- Woven textiles, cordage, and twine
- Pulp and paper
- Extenders for plastics
- Absorbents

Whole plants
- Timber, leaves and shoots for construction, furniture, fencing, packaging and protection, shelter, vessels, pilings, cooperage
- Energy by combustion of whole plants and their derivatives (*e.g.* fuel wood and charcoal)
- Cork for seals, gaskets, flooring, insulation, and floats
- Fumatories
- Pollution control of land, air and water, including control of particulate matter, noxious and toxic chemicals, noise, sewage
- Hydrological management
- Ground stabilisation and reclamation, shelterbelts
- Soil treatment, including composts, green manures, and mulches
- Carbon dioxide management (Kyoto Protocol)
- Visual amenity – the living landscape
- Habitat structure, including recreational habitats (domestic, urban, parks)
- Decoration

Speciality extracts and preparations
- Colourants and dyes
- Disinfectants
- Antibiotics
- Dentifices
- Preservatives
- Essential oils
- Insect attractants and repellants
- Masticatories
- Odours and perfumes
- Personal care and beauty products
- Plant-protection compounds and mixtures
- Polishes
- Resins and varnishes
- Rubber and balata products
- Astringents
- Sweeteners
- Medicinals (depressants including sedatives, narcotics and tranquilisers, psychodelics and hallucinogens, stimulants, analgesics, emetics, laxatives, cathartics, birth-control agents, purgatives, ointments, liniments, anthelmintics, *etc.*)
- Sizings
- Rayon
- Leather manufacture
- Insulators
- Acid-resistant receptacles
- Plant growth regulators
- Popular health-care products

Many species can have dual-purpose food and beverage, and non-food uses. Primary production sources from agriculture, horticulture, forestry, and from natural and semi-natural habitats. See IENICA http://www.csl.gov.uk/IENICA/index.htm

Table 6 Uses of Non-Food Annual and Perennial Angiosperms and Gymnosperms

mainly in rural areas. Strategies to encourage the use of alternative fuels to lessen the dependence on oil-based and fossil fuels have been proposed over the past four decades. Biofuels, predominantly bio-diesel and bio-ethanol, but including bio-methanol, bio-oils, and bio-gas could displace fossil fuels but will not be able to establish a proper market foothold unless there are changes to fuel taxation, introduction of more emission controls, and encouragement to meet Kyoto targets. Major scientific, engineering, and technological advances are possible, focusing on the generation of improved cultivars, agronomy, harvesting and processing, storage, combustion, and energy conversion and storage. The topic is a potentially rewarding area for innovation and creation of intellectual property (IP), but requires multidisciplinary effort. To date, most effort in the UK has been expended by the public sector with little focus on encouraging the creation of IP. A pertinent source of reference in this topic is *The Technology Roadmap for Plant/Crop-Based Renewable Resources 2020 : A Vision to Enhance U.S. Economic Security Through Renewable Plant/Crop-Based Resource Use* (http://www.oit.doe.gov/agriculture/), prepared by Inverizon International Inc. on behalf of the

Renewables Vision 2020 Executive Steering Group, published in January 1998. **2001-2002.**

Organic Farming Organic farming, on the one hand, raises risks of faecal contamination not only of foodstuffs but also of waterways, food poisoning, high levels of natural toxins (*e.g.* aflatoxins) and allergens, contamination by copper- and sulphur- (contaminated with lead) containing fungicides, production of blemished, diseased, and irregular produce of low consumer and food-processing acceptability, low productivity, and creation of reservoirs of pests and diseases, including sources of weed propagules. On the other hand, regenerative agricultural management systems based on organic fertiliser can preserve carbon and nitrogen in the soil, thereby reducing greenhouse-gas emissions, dispense with synthetic agrochemicals, and sustain on-farm, in-field biodiversity. In Europe, where the middle classes spend less than 15% of their income on food, and may even expect organic agriculture to be subsidised, and suffer from a surfeit of foodstuffs, organic agricultural systems have viable market niches. In LDCs, however, where more than 70% of income is spent on food, and production perturbations caused by pests, diseases, weeds, and bad weather lead to starvation and even suicides, there is a profound requirement for improving agricultural productivity and efficiency, and biotechnological approaches, including GM crops, are real options. The marketplace will ultimately determine the success and scale of organic farming enterprises, perhaps rapidly after the furore on GM crops has subsided. Competition between organic farming units will lower any price premium, and low productivity will give economic stress to small-scale producers, well-meaning and sincere as most of them are. D.T. Avery of the Hudson Institute pointed out that data from the Centers for Disease Control in the USA indicated that consumers of organic and "natural" foods were eight times as likely to be attacked by the new dangerous strain of *Escherichia coli*, O157:H7. He made the important point that "unless the organic movement puts a voluntary ban on the use of animal manures on food crops, certifies its compost as free of deadly bacteria or irradiates its produce, the health authorities should step in. In the deadliness contest, the bacteria are beating pesticide residues by a score of hundreds to zero". Manures are also associated with protozoan (*e.g. Cryptosporidium*), nematode, and other parasitic infections. The UK Soil Association, the organic farming organisation in the UK, bans the use of sewage which in some conventional farming systems is used in the raw and partly treated state. **1998-1999.**

Crop Protection Industry The crop protection industry in 1998-1999 underwent further changes with mergers, acquisitions, and strategic alliances. Many companies continued the trend towards greater specialisation and outsourcing of functions, especially in R&D and manufacturing of active ingredients, paralleling the trends in the pharmaceutical industry. Herbicides maintained a dominant rôle in crop protection in MDCs. Around 80% of the crop protection market was accounted for by the ten leading companies (in order of 1997 sales: Novartis, Monsanto, Zeneca, DuPont, AgrEvo, Bayer, Rhône-Poulenc, Dow AgroSciences, Cyanamid, and BASF). New combinatorial chemistry techniques, coupled to automation of biological screens and functional genomics, have revolutionised the search for new agrochemicals and other products by the agrochemical industry. Contrary to the impressions given by organisations campaigning against multinational companies, around 70% of the £23 billion global seed trade during the year was controlled by public-sector bodies; of the remaining 30% of the market there were about ten major international companies and numerous small-scale companies operating within countries. Nonetheless, the competition authorities are alert to possible market abuse, especially with the recent involvement of biotechnology and patenting. **1998-1999.**

Pesticides Pesticide usage will be severely curtailed in the EU in 2003. The EC will withdraw 320 pesticides, including fungicides, herbicides, and insecticides, in the light of manufacturers declining to defend their products for economic reasons, a process arising from notification procedures introduced during 2000-2001. There is the possibility that a further 150 substances could be withdrawn in July 2003. Thus, more than 60% of the substances on the market in 1993 will have been withdrawn; safety assessments on all the remaining defended substances should be completed by 2008. The current state of plant breeding, and the known propensity of pests and diseases to circumvent resistance mechanisms, ought to engender a search for new-generation crop-protection agents, but the European agricultural scene is generally not favourable to widespread investments in this area.

A particularly contentious area – bedevilled by strong opinions unfounded on fact, intolerant opinions expressed by certain farming and environmental pressure groups, unprofessional behaviour, and lack of understanding of agriculture – is that of a risk-benefit analysis of the use of plant-protection products (PPPs).

R. Bates, former head of Pesticide Registration and Surveillance Department in the former Ministry of Agriculture, Fisheries and Food noted that the public perception of the nature and magnitude of the health risks associated with pesticides is so at odds with available facts that it has become increasingly difficult to distinguish fact from fiction. Many have noted the disconnection between market demands for zero- or low- usage of pesticides with the maintenance of food supplies all-year round, with healthy and safe produce. Pesticides are used in organic and conventional agriculture with the aim of preventing yield losses from weeds, pests, and diseases; to protect or improve the visual appearance, quality and safety of harvested agricultural produce; to protect plant products in storage; and to improve agronomic efficiency and competitive position. Efficiency gains in agriculture make available relatively low-priced, high-quality plant products throughout the EU as well as lessen the demand for cultivated land, reduce energy-demanding erosion-inducing tillage, reduce waste, and sustain profitability. The consumer-led marketplace decides on the acceptability and value of plant material. For very good reasons – the presence of anti-nutritional compounds and the depletion of vitamin C levels – consumers avoid diseased and blemished produce. Some of the attacking microorganisms themselves produce toxins. Losses due to pests and diseases, both in the field and the store, can amount to 40% of total food production. The level of safety testing of modern pesticides if applied to many staple foods would cause them to fail. Some of the chemicals permitted for use in organic-farming systems would also fail, and the various plant extracts that are allowed (*e.g.* neem, pyrethrins, rotenone, tobacco), do not have established maximum residue levels in crops. B. Ames and colleagues have noted that 99.99% by weight of the crop protection products in the American diet have been synthesised by the plants themselves. Only 52 of these naturally occurring compounds have been tested in high-dose cancer tests and about half are rodent carcinogens. They estimate that Americans eat 1.5g of natural crop protection compounds *per* person *per* day, some 10,000 times more than any synthetic crop protection compounds they might consume. Syngenta Crop Protection UK Ltd. have produced a useful booklet on this topic, *Gaining Consumer Confidence : Residues of Crop Protection Products in Food*, by N.A. Atreya, C. Turner, and P. Parsons, May 2002.

Nonetheless, most PPPs are intrinsically dangerous (see Directive 67/548/EEC, Health and Safety Executive (HSE) *Agriculture and Wood Sector. Pesticide Incidents Report 2000/2001*) but it has proved difficult to quantify in monetary terms the actual adverse effects of PPPs. Human health can be affected acutely or chronically by direct exposure of those producing, applying, or consuming pesticides, or advertently coming into contact with them. According to the UK HSE, in the year 2000-2001 there were 170 pesticide incidents, 71 of which were alleged to have caused ill-health. Particular emphasis has been placed on those categories of the population regarded as sensitive, namely the elderly, the sick, and children, as well as those likely to encounter prolonged exposures. Drinking, surface, ground, and irrigation waters are subject to monitoring procedures. The most commonly identified pesticides in groundwater are atrazine and simazine. Persistence of active compounds and their bioaccumulation on the food chain, leading to possible adverse effects on human health (*e.g.* carcinogenicity, mutagenicity, genotoxicity, endocrine disruption) and indirect effects on the environment (principally loss of biodiversity) are active areas of research and monitoring, but there are remarkably few reports globally on pesticide-induced ill-health in consumers of agricultural products. Bad practice in the production and selection of pesticides, applications that lead to diffuse pollution or excessive doses, contamination after applications often through the cleaning of equipment, and disposal of surplus pesticides, their containers, and protective clothing pose risks. These are exacerbated in LDCs where there may be less-strict monitoring systems, reliance on old-fashioned, broad-spectrum toxic compounds, imprecise application technologies, lack of protective equipment, and poor training, all manifestations reflecting financially stressed circumstances.

Reduction of risks associated with PPPs over their life cycle hinge on several factors, not least regulation, monitoring, packaging, and labelling, continual R&D, phasing out of pesticides with unacceptable effects, proper disposal systems, modified farming practices, and plant breeding to introduce new forms of resistance to pests and diseases. Risk assessments and their limitations are discussed in the *Communication from the Commission on the Precautionary Principle* (Com (2001)1 final). Complexity arises, however, from the formulation of active ingredients with other active ingredients, various adjuvants, carriers, diluents, and supplementary fertilisers, leading to poorly understood additive or synergistic effects.

The Council Directive 91/414/EEC over-optimistically initiated a 12-year programme to review all bioactive substances in the EU marketplace, but the *Report from the Commission to the European Parliament and the Council on the evaluation of the active substances of PPPs* (Com(2001)444 final of 25.7.2001) recognised the enormity of the task and requested a postponement of the deadline to July 2008. The request was approved. **2001-2002.**

Intellectual Property and R&D

Patent Law In *Love à la Mode, II.* I, Charles Macklin, the Irish actor and dramatist (*circa* 1697-1797), wrote that: "The law is a sort of hocus-pocus science, that smiles in yer face while it picks yer pocket; and the glorious uncertainty of it is of mair use to the professors than the justice of it". Patent law is very complex and expensive. **1998-1999.**

Patenting Strategies Patenting costs, including associated litigation and licensing arrangements, mean that most public sector R&D bodies and all but the most affluent companies have to review constantly their patenting strategies and tactics. Failure to patent could mean that one or more competitors could gain the patent and protect it by closing off a market or demand licensing fees. On the one hand, failure to patent properly often means that incremental improvements and derivatives have to be patented too, or the original patent becomes surrounded or "picket-fenced" by competitors. On the other hand, existing and potential competitors can be disqualified from patenting by "defensive" publishing of information about the invention so as to create "prior art". In order to facilitate this defensive strategy, specialist journals such as *Research Disclosure*, websites such as *IP.com,* and its associated *Priorart.org*, and others act as public disclosure routes, with ready access to patent offices. Defensive publishing of incremental improvements could stop picket-fencing, but may have several drawbacks. Thus, it could be used to undermine or even dismantle the patenting system, adversely affecting investments in research-intensive organisations and technology-transfer companies, and quelling enquiry and investments more generally in innovation. **2000-2001.**

IP Protection by Defensive Publication Country-by-country translation and registration fees, annual renewal fees, the absence of a proper central court of patents, and inconsistent decisions dog entrepreneurial and commercial initiatives in the EU. Patenting within the EU remained a protracted and expensive process compared with the USA. In order to safeguard public access to research innovation and ensure full exploitation of intellectual property (IP), the strategy of 'defensive publication' has arisen in which scientists disclose details about their innovation to the public, thereby preventing others from gaining patent protection. This strategy is not confined to the public sector; commercial companies use it to prevent or forestall competitors from gaining advantage. In *Defensive Publishing : A Strategy for Maintaining Intellectual Property as Public Goods*, by S. Adams and V. Henson-Apollonio, International Service for National Agricultural Research (ISNAR), Briefing Paper 53, 2002, the strategy is outlined (see also *On the defensive about invention*, by R. Poynder, Financial Times, September 19, 2001). Guidelines on how to provide a robust defensive publication include (a) a complete and comprehensive description of the entire innovation or concept, (b) the use of the research product or innovation, (c) the publication must be made available to the public – especially accessible by patent office examiners, (d) the essence of the work must be brought to the public quickly and/or predictably, (e) it must be possible to prove the date on which publication was disclosed to the public, (f) it may be possible to defer surrender of all or part of the property rights. There are two main routes to defensive publication: (a) self-publishing through company publicity materials, company report series including websites, occasional publications, and possibly ephemeral literature, or (b) more to be preferred, third-party publishing such as commercial public disclosure (*e.g. Research Disclosure* (www.researchdisclosure.com), the peer-reviewed literature, national publications (*e.g. Statutory Invention Registrations* of the US Patent and Trademark Office), and other IP titles, such as the utility model system (*e.g. Gebrauchsmuster* in Germany). **2001-2002.**

GM Approvals To bring a GM crop and its products to the market-place in the EU involves a frustrating jungle of legislatory and regulatory procedures, causing uncertainty and risk to companies, investors, and employees. The whole approval process is at least twice as long in the EU as in Japan and the USA. In theory, the principles of relevant legislation are (i) not to prevent the supply of safe, wholesome foods; (ii) permit the free movement of products in a single market; (iii) to reflect changing consumer demands; (iv) to be based on sound science; (v) to be enforceable, and (vi) protect human health and the environment from possible undesirable effects of GMOs. **1998-1999.**

GM and non-GM IP Oppressive intellectual property (IP) rights; restricted access to foodstuffs; the neglect of medicines, dietary nutrients and crops crucial for LDCs (the so-called low-profitability 'orphan' products and crops); focus on just one essential technology to the exclusion of other, more conventionally but less financially attractive technologies; pressure to downgrade regulatory processes; market policies which are overtly not pro-poor even to the extent of not boosting the economies of LDCs; and the perceived lack of consumer benefits have all been raised as reasons to retard the advance of biotechnology. The CGIAR system agreed in 1998 to a statement of ethical principles underlying the use of biotechnology by its various Centers. Emphasis was placed on its objectives, transparency of operation, commitment to fairness, honesty, integrity, intellectual rigour, accountability, and precautionary approaches to genetic resources. Interestingly, the statement made reference to the fact that the CGIAR is guided by its particular humanitarian and equity-based concerns, and not to the pursuit of knowledge for its own sake. Fundamental concerns about the sacred and inviolate nature of life forms and their ownership ('core values') are more problematical for scientists knowledgeable about genes, functioning in a pluralistic society, and cognisant of perpetual human intervention in food production, environmental modification, and the domestication of pets, livestock, and crops. Blatant disregard for such perceptions and sensitivities would be wholly unjustified, however, given the exquisite sophistication and unquantifiable value of all life forms, and the fascination they hold for all biologists. For some members of society, biotechnology represents an example of the unacceptable rapid rate of progress and societal pressure, with alien vocabulary and techniques. Hitherto, society has evolved almost imperceptibly in tune with its foodstuffs and cultivars – but this is no longer the case, nor can it be. Whereas it is justifiable to argue that the unfettered pursuit of knowledge and understanding is intrinsically good for humanity and the progress of scholarship, it is my firm view that scientists must be interested in and concerned about moral, ethical, and social issues that result from their studies, and be willing to comment publicly on them. As science, engineering, and technology are increasingly shaping the development of civilisation, human interrelationships, and the environment, there is now unprecedented analysis of science, the attitudes of scientists, and their responsibilities for the applications of their work, often without the participation of scientists themselves. Elements of originality, professionalism, integrity, pragmatism, rationality, responsibility, erudition, openness, independence, strength of character, and determination to function for the betterment of humanity, are all required by scientists, overarching any short-term functions or bending to political or popularity pressures, regardless of discomfiture caused.

Related to ethical aspects of ownership is market-place ownership and the concept of intellectual property (IP) as categorised by plant variety rights, patents, trademarks, copyright, designs, licences, and trade/commercial secrets. All categories of IP offer market advantages and certain disadvantages, some more than others. Patents, above all, exercise consumer groups, anti-capitalists, and those representing the poor. On the one hand, patents provide the owner of that patent with monopoly commercial rights to the invention for a limited period, usually not exceeding 20 years, and only in the country that grants that patent. This offers the owner an opportunity to recoup R&D costs, legal, manufacturing and marketing costs, plus the opportunity to make a profit. Without the prospects of monopoly rights and the incentive to make profits, expensive-to-develop technologies would never enter the marketplace. It is the special feature of industrialised economies that they have rigorous IP regulations, which in turn provide a main driver to the operation of capital markets, safeguarding the rights of patent owners and incentivising technological developments. The monopoly position achieved by the patent holder is at the price of public disclosure of the invention to enable other scientists, engineers, and technologists to use the invention in their research, and for the public and society to benefit from the acquired knowledge. Membership of the WTO enables a minimum-level measure of harmonisation of legal frameworks across national borders under the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs), which should start to apply to relevant LDCs by 2005 and, in this regard, the World Intellectual Property Organisation will provide technical assistance and training. In the area of genomics-based biotechnology, there are certain developments that will be the subject of a large period of legal debate, exacerbated by a complex of overlapping patents. Much hinges on Article 27 of TRIPs which provides for the availability of patents for any inventions (products, processes, systems *etc.*) in all fields of technology provided that they are, new and not obvious, involve a demonstrable inventive step, and not least, are capable of industrial application. The legal costs of sustaining a dormant IP portfolio cannot be justified in public-sector bodies, other than to ensure the exploitable availability of the technology and to prevent a monopoly position from being taken in vulnerable LDCs. Certain provisional patents in biotechnology would appear to be discoveries rather than inventions, and some are obvious and may be formulated to inhibit the patent positions of others: such may be the basis of future patent challenges.

Human ingenuity and considerable expenditure can be involved in isolating and patenting naturally occurring genes, but if specific uses/functions cannot be ascribed for those genes, especially in broad-sweeping claims that overlap with other patents (a feature of the US Patent Office), then there must be doubt as to the validity or longevity of such patents in the international arena. There have been claims that the agricultural biotechnology industry is transforming into a small number of multinational companies that could monopolise world food supplies. At present, though, around 70% of the world seed trade is controlled through the public sector. Nonetheless, for three of the major staple crops (maize, wheat, potato), more than 3000 out of a total of 3500 patent applications for gene sequences have been filed by nine companies (Affymetrix, AstraZeneca, Aventis, Danisco, Dow, Du Pont, Monsanto, Novartis, and National Starch). There is obviously a fundamental difference between a patent application and a patent awarded, and even after being awarded, expensive defence of the patent may be needed. To this uncertainty must be added the effects of delaying market releases, reducing the opportunity even to recoup costs.

One of the potential downsides of intellectual property rights (IPR) enforcement for transgenic organisms and biological materials containing genetic information is their ability to self-reproduce, but molecular-fingerprinting techniques for monitoring and policing purposes provides a valuable tool for detecting both transgenic and conventionally-bred organisms and their transgenic-gene-linked products. For LDCs, concerns have been expressed about the patent system at levels *viz.*: (i) increased costs to cover royalties, alone considered to be a factor in prompting the tendency to avoid IPR strictures; (ii) jeopardised existing indigenous industries, products, and services; (iii) hidden constraints on local R&D efforts regardless of the fact that the patent system should not infringe the freedom to use patent information and products for research purposes, indeed IPR enforcement will give confidence to donors that IP will be safeguarded; (iv) misgivings and misconceptions over the loss or theft of indigenous natural resources including know-how by MDCs (see *The Commercial Use of Biodiversity. Access to Genetic Resources and Benefit-Sharing* by K. ten Kate and S.A. Laird, a report for the EC published by Earthscan 1999) contravening the provisions of the Convention on Biological Diversity; (v) lack of information about patents being issued, and the costs and complexities of challenging patents internationally – concerns shared by MDCs; (vi) specific technologies such as genetic use restriction technologies or even biotechnology itself could be regarded as unethical or immoral absolutely, or just unethical and immoral when used in a capitalist context. Fortunately or unfortunately, depending on the philosophical standpoint taken, the market-place will decide. Knowledge comes at a price.

As discussed in previous SCRI reviews, the UPOV convention (the International Union for the Protection of New Plant Varieties) has been widely regarded as a reasonably efficient mechanism for dealing with the entry and use of conventionally bred cultivars in the marketplace. The rights of breeders, researchers, and farmers are protected. Transgenic modification of existing cultivars to address certain market niches needs a fresh appraisal, and review of the interrelationship with patent law and rewards to the IP owner. Of greater potential concern, but necessary for orderly development of most capital markets, is the existence of commercial secrecy arrangements which could lead to cartels and suppression of essential knowledge. Balancing the rights and needs of individuals, companies, the state, and trading blocs, is awkward, but the increasing tendency for scientists of all affiliations to be more conscious of the wealth-creating possibilities of their work, places special responsibilities on them to ensure that high professional standards are applied. **1999-2000.**

Agbiotech IP Agricultural biotechnology (agbiotech) experienced difficulties in IP matters internationally, mainly in restricted access to IP (or lack of freedom to operate), variable regulatory regimes, overlapping patents and patent claims, inadequate technology-transfer systems, and the burden of transaction costs associated with convoluted IP rights. Almost akin to orphan medicines, minor crops (especially horticultural crops) and many crops which are essential for life in LDCs are for the most part ignored in agbiotech R&D programmes in the MDCs. Helpful proposals to improve the situation were made in *IP Strategy Today No. 3-2001* (see http://www.bioDevelopments.org), including IP "clearinghouses" to reduce the complexity and transaction costs of the "patent thicket" and IP "aggregators" for bringing together smaller interested parties, as well as for mutually interdependent patents over a common technology system scattered across multiple parties. As pointed out in *Slow Magic. Agricultural R&D a Century after Mendel* by P.G. Pardey and N.M. Beintema, International Food Policy Research Institute, 2001, there are 114 members of the Patent Co-operation Treaty administered by the UN World Intellectual Property Organisation. All 141 members of the WTO must comply with the terms of the Trade-Related Aspects of Intellectual Property by 2005. Moreover, 49 countries, including 28 LDCs, are signatories to the UPOV Convention (the International Union for the Protection of New Plant Varieties) that provides certain rights to plant breeders. **2000-2001**.

Entrepreneurialism During recent years, there have been numerous attempts to emulate the entrepreneurial culture of the USA. In the USA, the enterprise culture is inculcated into the framework of society with more than one in 12 people, or a third of households, having a family member who has started a small business. The US tax system and public attitudes encourage risk-taking, business regulation albeit tough is flexible, and support services for new firms (lawyers, accountants, estate agents, and planners) are perceived as helpers rather than hinderers. In preparing to launch the Small Business Service, based loosely on the highly effective American Small Business Administration, the UK Government planned for the new service to act as a voice for small firms, to simplify and improve governmental support, and monitor regulations. According to The Global Entrepreneurial Monitor, only 16% of people in the UK thought there were good opportunities to start a business in the near future compared with 57% in the USA. Attitudes to the status of entrepreneurs, too, were much more negative in the UK than in the rest of the world, and there was evidence that the UK was losing its entrepreneurial edge. Counteracting entrepreneurial behaviour in the UK, however, was the increasing bureaucratic burden placed on industry. Small businesses will not be exempt from administering the new stakeholder pension. Together with the newly imposed working time directive, the national minimum wage, the fairness at work proposals, and the administration of the new working families tax credit, it was estimated that the cumulative effect of such measures will add £4.6 billion to business costs and ultimately eradicate 880,000 jobs, according to P. Minford and A. Haldenby in *The Price of Fairness*. **1998-1999**.

R&D Investments For many years, it has been clear that R&D is a key to successful growth; companies with above-average R&D spend tend to show above-average sales-growth, productivity, and market value or shareholder return. Companies mainly grow by acquisition or by organic means through R&D or other investments. The acquisition route is frequently much inferior to the organic route in terms of total shareholder return, although it has been the preferred route in recent times. Even so, competitive advantage requires a suite of attributes: management and worker skills, capital investments, market development, originality, adaptability, and commitment. The annual *Scoreboard* report published by the UK Department of Trade and Industry recognises that its analysis is not and cannot be comprehensive. It does not include companies that undertake R&D but do not declare the amount invested in their accounts, nor does it include UK companies investing less than £260,000 *per annum* in R&D. Importantly, it excludes publicly funded R&D but it would be useful to try to relate this component of R&D expenditure to the various FTSE sectors, and to assess the societal impacts of that R&D over a suitably long period, *e.g.* 30 years or more. It is the aspiration of government and scientists that the various incentives for R&D investment in addition to improvements in the science base and business environment should accelerate the process of success through innovation. The UK needs more middle-sized companies in the high-R&D sectors, and more of them with high R&D intensities: it is from this category that the new major international companies will emerge. As market valuations decline, however, there is increasing danger of mergers and acquisitions by companies from overseas competitors, or a shifting of decision-making staff to other countries, or even a firesale of potentially valuable intellectual property. **2001-2002**.

Agrochemicals 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, tax, depreciation, and amortisation) 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. **2002-2003**.

GM Crops and Plant Biotechnology

Biodiversity The single largest threat to biological diversity arises from the conversion of natural habitats or native lands to urban development or to agriculture, often with monocultures, or their ecological near-equivalents. After this threat comes the dangers from habitat degradation through pollution or unsustainable extractive practices such as large-scale logging, overfishing, and mineral extraction. Against this background, the threat to biological diversity from the products of modern biotechnology is infinitesimal. But what if all the products presently in the R&D pipeline were now on the market? Nearly all the new crop cultivars being produced with the techniques of modern biotechnology have been modified or selected using biotechnology to sustain or increase yields, whether through imparting to them resistance to pests or diseases or through increasing their ability to withstand competitive pressures (or to eliminate such pressures) from, for example, weeds or other biotic or abiotic stresses. It has been argued that if the genes added to existing cultivars to impart such characteristics were to flow (generally by sexual recombination) into wild or weedy relatives, weed problems could be exacerbated or wild, pristine gene pools could become contaminated. In the vast majority of cases, however, the pests or diseases detrimental to agricultural yields are not the limiting environmental constraints on the wild relative being receptive to out-breeding from the domesticated cultivars. Experience shows that selection pressures found in nature do not favour such gene flow from modified crops to wild relatives. A far more likely path through which potential characteristics or traits from genetically modified crops could have an impact on biodiversity is, in the absence of constraining population growth, by decreasing the rate of habitat loss through increased yields. The most likely impact on biodiversity from novel crop varieties, therefore, is to alleviate the main threat. **1996-1997.**

Biotechnology Concerns Concerns about biotechnology relate to nine main areas.

1. Even though genetic modification was the first technology to have a raft of controlling legislation in place to ensure human health, and environmental safety, well before the first products reached the market place, environmentalists have expressed concern at the lack of statutory post-approval monitoring when GM crops move from field trials to commercial production. Others have reservations over the lack of uniform and comprehensive international standards for GM regulation, approval, and labelling.

2. The widespread use of genetic modification might lead to the erosion of biodiversity, with increased dependence on a narrowing range of agricultural and horticultural crops. Biotechnology, however, provides the tools to measure and extend biodiversity, and improved crop performance reduces pressure on fragile habitats.

3. Not enough is known about how ecosystems work, and the release of GM crops could have disastrous consequences. GM crop release could disrupt the environment through the undesired spread of a modified crop, by transfer of chemical or pathogen resistance to weedy relatives, or the unexpected production of harmful toxins. World-wide, GM crop releases to date prove otherwise, but monitoring is essential.

4. Herbicide-tolerant crops may tie farmers in to seed-agrochemical packages, possibly leading to increased herbicide use and the risk of herbicide-tolerant crops and their genes spreading into the wild environment. Of course, herbicide tolerance exists in conventionally bred cultivars, and experience of herbicide-tolerant GM crops, albeit only over a short time scale, shows major environmental benefits in reduced herbicide usage. US farmers report a 5% yield rise and 33% less herbicide use in Herb® GM soyabean crops.

5. Using biotechnology to develop pest- and disease-resistant crop varieties could possibly lead to the creation of new pests or diseases, or the transfer of resistance to wild relatives. This has not been shown to be valid to date, but monitoring is required.

6. Herbicide- and antibiotic-resistance genes used as markers in the GM process might be transferred into the environment or human food chain. Many of the marker genes were only required in the early steps of breeding selection and have been superseded; to date, there are no unacceptable risks.

7. Biotechnology could inadvertently result in higher levels of human toxins, a reduction in beneficial nutrients, unexpected allergic reactions, or even the inducement of long-term metabolic consequences. This is an area for the regulatory authorities.

8. For some religious and other groups and individuals, biotechnology is 'unnatural', 'ungodly', and unacceptable ethically and morally. Strongly held views are difficult to change and democratic rights must be expressed to ensure safeguards. A UN code of bioethics is expected in 1997. It is really the threat of misuse of genetic engineering that raises questions of ethics.

9. Some patent protection relates to discovery rather than invention, and some patents are unacceptably broad-spectrum, oppressing releases of competing products or organisms. In their decision in the Biogen *v* Medeva biotechnology case, the House of Lords in 1996 considered priority dates, the need for the specification to contain an 'enabling disclosure' to allow the invention to be performed over the full width of the claims, the date at which the specification would be sufficient, and obviousness. Broad claims in future will be difficult to sustain legally without adequate enabling disclosure. **1996-1997.**

Dolly In February 1997, the team led by Ian Wilmut at the Roslin Institute in Edinburgh and PPL Therapeutics gained world-wide publicity surrounding the birth of a live lamb, 'Dolly', developed from a single cell originating from a mammary-gland cell line taken from an adult sheep. Dolly, whose picture graced front pages and covers of newspapers and journals, was the first mammal to be asexually cloned by transferring the nucleus from a donor sheep cell, cultured *in vitro,* to an unfertilised sheep oocyte from which the nucleus had been removed. As a consequence, Dolly was (with due allowance for cytoplasmic effects) genetically identical to the sheep from which the donor nucleus had been taken. This excellent research was disgracefully and inaccurately projected by certain sections of the media and various zealots. Hastily drafted legislation to ban human cloning, rather than introduce a brief moratorium, was effected in many countries, obstructing highly desirable aspects of human cloning, such as skin grafts, drug production, and 'spare-part' organs. As an editorial in *Nature* points out, the history of science suggests that efforts to block its development are misguided and futile. The quest for knowledge is inevitable; the responsible deployment of knowledge, however, presents the greatest challenge to modern society, and to those who cannot comprehend, adapt to, or benefit from change.

It should be pointed out that for thousands of years, plants have been asexually cloned from cuttings, off-shoots, corms, bulbs, rhizomes, tubers, stolons, and buds. Modern biotechnology, in tandem with tissue, organ, and single-cell culture systems, make plant cloning more efficient, more predictable, and invaluable for phytosanitary, mass propagation, and phytochemical purposes. Selective nuclear and organelle additions and subtractions are revealing the rôles of the various cellular components. By introducing a dedifferentiation phase, it is possible to create valuable and fascinating somaclonal variation. **1996-1997.**

Plant Biotechnology The OECD defined biotechnology as "the application of scientific and engineering principles to the processing of materials by biological agents". More formally, biotechnology refers to the application of organisms, sub-cellular entities, or biological processes, to manufacturing and service industries, including agriculture, horticulture, forestry, human and veterinary medicine and pharmaceuticals, food production and processing, and environmental management such as bioremediation. The aims of the technology encompass: biomass production; production of chemicals and useful products; purification of water; decomposition of wastes and recovery of valuable components; generation of new types of organisms; exploitation of fermentation; diagnosis, prevention, and treatment of diseases; unravelling metabolic pathways; and propagation of cells and whole organisms. Recent technological and intellectual advances in molecular genetics – particularly sequencing of genes and proteins, isolation and insertion of genes into receptor organisms, development of marker genes and promoters, and gene amplification – have given rise to the "new biotechnology". The techniques of biotechnology are being used in fundamental research in the life sciences, and the divisions between plant, animal, and microbial biotechnology are becoming increasingly irrelevant. **1998-1999.**

Related Sciences and Technologies New interfaces within biotechnology include those with information technology (bioinformatics), chemistry (new separatory and identification systems, novel biomaterials), physics and engineering (gene chips), electronics (biomolecular computing and molecular design), and nano-scale engineering and medicine (molecular-scale surgery, tissue engineering) *etc.*. A new branch of biotechnology in both the private and public sectors has achieved special prominence – genomics, which covers structural genomics (determination of the complete nucleotide sequence of a genome and identification of its genes) and functional genomics (characterisation of gene function on a genome-wide scale). Most plant genomes are largely unexplored. In view of the fact that genes are studied in groups in parallel, computational analysis of the data, *via* bioinformatics, is central to any genomics strategy, which will concertina the time to bring discoveries and inventions to the marketplace. Biotechnology in all its guises affects all areas of human activity, and no nation can afford to ignore the huge potential of the range of biotechnological developments coming on stream. **1998-1999.**

Impedence of GM technology Pejorative and wholly unjustified language such as "Frankenstein Foods", "unwanted", "contamination", and "genetic pollution" was used to stimulate negative emotions in Europe. Rational and detailed debate was rare. Not surprisingly, whilst the area of GM crops expanded in the rest of the world, commercial plantings of transgenic cultivars were constrained in Europe. The UK introduced a one-year ban on commercial plantings, and a three-year ban on GM insect-resistant crops. A ministerial committee was proposed to oversee policy developments relating to biotechnology. In August 1998, the French government imposed a two-year moratorium on the planting of GM oilseed rape, and in December, established a permanent "biovigilance" committee to examine the safety and environmental impact of GM crops. Also, in France, there were legal appeals against the approval of GM maize lines from three companies, and the authorities did not ratify a GM oilseed rape cultivar that had received EU authorisation in June 1997. The Greek government banned the import and marketing of a glufosinate-tolerant oilseed rape, despite EU authorisation. Similarly, Austria and Luxemburg proved a hostile environment for the trialling of corn-borer-resistant maize; the European Parliament and Commission agreed in December 1998 to postpone attempts to overrule the bans imposed by both countries. In contrast, only 70,000 signatures were collected for a petition to ban all GMOs, and in June 1998 Swiss voters rejected with a majority of 67% a proposal to restrict biotechnology in agriculture and medicine. **1998-1999.**

GM Concerns In the GM debate, the main concerns were possible (i) risk to human health, (ii) risks to the environment, (iii) regulatory weaknesses, and (iv) ethical unacceptability. With regard to human health, in most countries the safety of traditional foods derived from plants is not regularly reviewed on the basis that foods consumed for generations should be safe as part of a normal diet. Even so, traditional foods contain natural toxins (*e.g.* lectins, glucosinolates, erucic acid, glycoalkaloids *etc.*). There are naturally occurring carcinogens in most plants, as well as carcinogens derived from (a) the frying, baking, and smoking of foodstuffs, (b) the products of microbial attacks of fruit, seed, and vegetables, and (c) the products of microbial spoilage of stored products. Nutritional and compositional screening tests and knowledge of the parental material will indicate the presence of toxins in the products of both conventional and GM breeding. Likewise, the possibility of allergenicity caused by alien genes can be readily detected. **1998-1999.**

Gene Flow Risks to the environment as a result of promiscuity by introduced genes leading to unintentional effects on non-target, possibly beneficial organisms, is a complex area. Gene flow at different levels can be detected in all crops, but where there are no native species with which to cross-breed (*e.g.* UK members of the Solanaceae and commercial potatoes), or where the incidence of cross-breeding is extremely rare, then there is no scientific justification whatsoever for assuming that gene flow from GM crops is any different from that which already occurs on a vast scale in conventional agriculture, horticulture, forestry, and domestic gardening, and which occurs in natural ecosystems. Nor is it justified at this juncture in assuming that the gene flow is invariably undesirable or harmful. As I have stated in previous *Reports of the Director,* new forms of agronomy involving refugia, dispersal corridors, buffer zones *etc.* will have to be introduced to reassure growers of organic crops, and retard gene-flow effects from introductions of all types. Questions have been raised about herbicide resistance/tolerance genes which might escape from GM crops into the natural flora, especially weeds, which would become difficult to control. Related to this is the use of herbicide on the GM crop leading to toxicological consequences in humans and wildlife, even though there is no evidence for this. As before, proper monitoring and regulatory processes must be in place, and in fact are equally applicable to applications of pesticides, fungicides *etc.* to conventional, organic, and GM forms of agriculture, horticulture, forestry, and gardening. **1998-1999.**

Pusztai One of the most cited scientists in the international GM debate has been A. Pusztai, formerly of the Rowett Research Institute in Aberdeen. By means of television, radio, newspapers, and the Internet, rather than subjecting his research to peer review, he claimed in 1998 that diets containing GM potatoes expressing the snowdrop lectin, *Galanthus nivalis* agglutinin (GNA), affected different parts of the rat gastrointestinal tract. Some effects were claimed to be due to the expression of the GNA transgene, but other parts of the construct, or the genetic transformation itself, or both, could also have contributed to the overall biological effects of the GM potatoes. The initial reports were announced as factual in press releases by the then Director of the Institute, W.P.T. James, and the Rowett Chairman, J. Provan. Shortly afterwards, Professor James launched an audit of the Rowett research on Pusztai's unpublished work. The report of the audit stated "The Audit Committee is of the opinion that the existing data do not support any suggestion that the consumption by rats of transgenic potatoes expressing GNA has an effect on growth, organ development or the immune function. Thus the previous suggestion that the research results demonstrated adverse effects from feeding genetically modified potatoes to rats was unfounded." In April 1999, the Royal Society convened a Working Group to examine whether the publicised but unpublished work would require changes to the Society's September 1998 statement on GM plants for food use. Six reviewers considered the available evidence and concluded that "the safety of GM plants is an important and complex area of scientific research and demands rigorous standards. However, on the basis of the information available to us, it appears that the reported work from the Rowett is flawed in many aspects of design, execution and analysis and that no conclusions should be drawn from it. We found no convincing evidence of adverse effects from GM potatoes. Where the data seemed to show slight differences between rats fed predominantly on GM and on non-GM potatoes, the differences were uninterpretable because of the technical limitations of the experiments and the incorrect use of statistical tests. The work concerned one particular species of animal, when fed with one particular product modified by the insertion of one particular gene by one particular method. However skilfully the experiments were done, it would be unjustifiable to draw from them general conclusions about whether genetically modified foods are harmful to human beings or not. Each GM food must be assessed individually. The whole episode underlines how important it is that research scientists should expose new research results to others able to offer informed criticism before releasing them into the public arena. In view of the public interest in this case we recommend that the results of any future studies on testing GM food safety, when completed, should be peer reviewed and then published. This would provide an opportunity for the international scientific community and the public at large to have access to the information."

In October 1999, S.W.B. Ewan and A. Pusztai published their observations and conclusions in a Research Letter to *Lancet*, accompanied by a pithy commentary from the Editor. Accompanying this commentary was a commentary by H. Kuiper and colleagues from Wageningen, and also a Research Letter from B. Fenton and K. Stanley of SCRI, and S. Fenton and C. Bolton-Smith of the University of Dundee, Ninewells Hospital and Medical School, on the binding of GNA to human white blood cells *in vitro*. Kuiper and colleagues pointed out that the experiments of Ewan and Pusztai (a) were incomplete, with too few animals *per* diet group, (b) did not report on the composition of the different diets, (c) lacked controls such as a standard rodent diet and a test diet with potatoes containing an "empty" vector, (d) did not observe consistent patterns of change, (e) did not deal adequately with possible adaptive changes in the gut because of the low digestability of raw or partly refined starch. Accordingly, Kuiper and colleagues concluded that "the results are difficult to interpret and do not allow the conclusion that the genetic modification of potatoes accounts for adverse effects in animals". They concluded that the work of Fenton and colleagues emphasised the need for further studies on the bioavailability of lectins and potential toxic effects once they have entered the systemic circulation.

The work conducted by Ewan and Pusztai was part of a collaborative study, funded by the Scottish Executive, on lectins and their possible use in protecting plants from pest attacks. The GM potatoes were not designed for commercial release into the food chain – the toxicity level of a wide range of lectins is well known and allowed for by avoiding poisonous species or by careful food preparation. Future work will undoubtedly consider expression of certain lectins in non-food crops, or confinement of expression in parts of food plants that are not consumed, or expression for specific periods during development, or expression only at the specific site of pest attack. As Kuiper and colleagues pointed out, unintended effects of genetic modification can be detected by screening for altered metabolism in the GMO by analysis of gene expression (monitored by microarray technology, mRNA fingerprinting *etc.*), by detailed protein analysis (proteomics), and by secondary metabolite profiling (metabolomics). These tests would be in addition to extensive toxicological and nutritional assessments. In truth, such tests could be applied in future to conventionally bred cultivars. What is clear, though, is that all current commercially available GM crops do not differ from the traditionally grown crops except for the inserted traits. As second- and third-generation crops come on stream (see later) then more stringent testing should be introduced. Obvious lessons to be drawn from the GM debate include the requirement for wide consultation with the support of authoritative literature; effective and non-pejorative food labelling and testing of all foodstuffs; research to address gaps in current knowledge; and absolute transparency and open access provided to the public and politicians. **1998-1999.**

Three Generations of GM Crops Rapid sophistication is taking place in the objectives or targets of the transgenesis processes.

1st Generation GM The first generation of crops is predominantly aimed at crop protection by resisting competititon from weeds by the introduction of herbicide-tolerant genes, usually deploying a single gene trait, or by resisting the depredations of pests and diseases. This strategy is still under refinement, extending the range of crops and genes, and addressing a wide range of pests and diseases. Stacking and mixing of genes is being introduced to overcome the possible build-up of resistance in the pest and pathogen populations.

2nd Generation GM Second-generation transgenic crops are aimed at improving directly yield efficiency and quality. Over the next five to ten years, large-scale crop introductions will probably focus on (i) modified carbohydrate quality for industrial feed stocks (binders, fillers, stabilisers, and thickeners) and improved food processing, (ii) vegetable oil content and quality, (iii) amino acid and protein content and quality, (iv) harvestable fibres with low lignin content, and coloured cellulosic fibres, (v) substrates for the bio-plastics industries, (vi) tolerance to biotic and abiotic stresses, (vii) better water- and nutrient-use efficiency, (viii) enhanced photosynthetic efficiency, (ix) reduction in the production of anti-nutritional and allergenic factors, (x) modified colours and shapes of fruit, vegetables, and flower crops, (xi) easier harvested crops by phenotypic modifications (*e.g.* synchronised maturation, improved abscission) and with improved shelf/storage life, and (xii) hybrid crop production.

3rd Generation GM Third-generation crops which may be grown on a large scale in the longer term tend to focus on phytoremediation of contaminated land and water, and on the production of nutraceuticals and pharmaceuticals. Environmental monitoring and the slow, methodical approach in carrying out dietary and clinical trials will of necessity delay the introduction of these fascinating crops and platform technologies currently under investigation. The second- and third-generation crops will have genes that are targeted at specific integration sites in the chromosomes; some will employ organelle transformation, virus vectors, switch technology and eventually also gene-use restriction technology (*e.g.* 'Terminator') which can not only protect the intellectual property by effectively preventing further propagation but stop inadvertent spread of GM to other crops. The problems of gene silencing, location in the genome, resistance breakdown, genetic instability and unexpected pleiotropic effects will continue to be addressed by screening in conventional trials, and by technological advances. The destabilising and often *misconceived* arguments about GM crops and GM food are already influencing investment strategies and may deprive the UK of proper participation in accessing and reaping the benefits of all branches of biotechnology. **1998-1999**.

Plant Science At a time when plant sciences in the UK are in marked decline, subject to a few prominent exceptions in the UK public-sector research institutes, such as SCRI, and some universities, the UK National Academy of Sciences recommended that urgent attention is given to the fundamental aspects of plant biology, especially molecular, cellular and whole-plant processes; ecology; and interactions between plants and other organisms. Plant science should also incorporate a global perspective. Advances in molecular genetics, mathematics; and environmental sciences have enabled the plant sciences internationally to be at their most intellectually and industrially buoyant ever. Nonetheless, a combination of (i) prolonged under-investment, (ii) unprecedented levels of bureaucratic "shaping" of research programmes, (iii) under-performance of undergraduate and postgraduate teaching, (iv) poor career prospects affecting recruitment and retention of outstanding scientists, (v) outdated public-sector attitudes that cause a pronounced lack of appreciation, or actual impedance, of technology-transfer initiatives that could introduce new resources and technologies, and (vi) a hostile funding and social environment for plant biotechnology, have all led to the current unsatisfactory position in the UK. Botany is an endangered scientific species. This also coincides with the sad position of most sectors of UK agriculture and horticulture which desperately need to generate profitability by (i) accessing those areas of science, engineering, and technology that enable them to be internationally competitive (*e.g.* improved cultivars, greater automation, ownership of intellectual property), (ii) proper customer focus, and (iii) linkage with industries that add value to primary produce. Valiant attempts by the Levy Boards (*e.g.* British Potato Council, Home-Grown Cereals Authority, and Horticultural Development Council) are diminished by the economic climate, but their rôles are central to the rejuvenation of their respective sectors of industry, especially if they are not destabilised by continual reviews and are permitted to have an adequate period to participate in generating protectable intellectual property. Fortunately, some areas of agriculture and horticulture attending to niche markets or meeting customer needs are still profitable, and many industries upstream and downstream of agriculture are particularly healthy. Biotechnologies relating to diet and health, forestry, the environment, and platform technologies are especially promising. **1998-1999.**

CAP and GM Crops Mankind has already entered the era of genetic commerce, but agricultural biotechnology (agbiotech) markets in Europe have been suppressed compared with other regions of the world. The main reasons for this situation are fivefold. (i) The CAP favours the inefficient with a mixture of production and marketing subsidies and compensation payments, leading to rural social therapy. (ii) A stable but rapidly urbanising population is becoming divorced from the realities of rural enterprise and demands a risk-free existence. (iii) BSE and food contamination issues have confused regulatory failure with scientific advances, and there has been a loss of confidence in scientists. (iv) Ignorance of biotechnology generally is profound in the population at large, and in most political and decision-making groupings. (v) There is a persistent suspicion of technology, profit-making, and multinational companies, aided by largely antibiotechnology news media. Not surprisingly, these factors have induced new legislation, burdensome regulation, potentially pejorative labelling, industry-wide codes of practice, and prolonged monitoring systems within the EU, mainly to satiate wantonly poorly informed, often paternalistic, political and pressure groups. Resources that could be spent on R&D and market development are being diverted not only to overbearing regulation and resource- and time-sapping bureaucracy in a zealous application of the precautionary risk principle, but also to security and protection from attacks against technology centres and GMO crops. **1998-1999.**

Agbiotech 1997-1998 A synopsis of the agbiotech industry worldwide in the financial year 1997-1998 shows it to be growing at a rate of around *20% per annum,* and receiving massive investments. It was also supporting huge research programmes in molecular genetics and proteomics. Between 40%-50% of all US crops will be transgenic; the global area of transgenic crops in 1997 was about 31.5 million hectares. In the period 1986-1997, there were 25,000 transgenic crop trials using more than 60 crops in 45 countries. At the end of 1997, 48 transgenic crop products involving 12 crops and 6 new traits were approved for commercial-scale release and commerce. To date, the technology has proved to be stunningly safe, especially in respect of human health and the environment. Many technological advances have been made since the early phases of deploying antibiotic-resistant marker genes. Ancillary non-transgenic advances were made in (i) diagnostics for pests, diseases, and quality traits; (ii) selection of parental material for rapid conventional breeding; (iii) techniques to measure and quantify biodiversity and gene flow; and (iv) development of novel approaches to produce pharmaceuticals, carbohydrates, oils, plastics, *etc.*. A common feature of GMO crops has been a reduction in inputs. **1998-1999**

Agbiotech and Agronomy New types of agronomy will have to be developed to respond to the disquiet of environmentalists. Release and monitoring trials will need to be approved on a case-by-case basis. GMO crops will require proper segregation to lessen the possibility of gene flow ("genetic pollution"). Refugia and dispersal corridors *(e.g.* wide hedgerows) for the natural flora and fauna need to be safeguarded and developed, a point which I have advocated for several years and which I included in the Delphi questionnaire for the Agriculture, Natural Resources and Environment Sector Panel of the UK Technology Foresight exercise. Monitoring systems should be in place anyway, not only to check on the performance and impact of GMO crops but to determine the impacts of new pests, diseases, plants, and animals introduced, most frequently by domestic horticulturalists. Any new technology, (*e.g.* aircraft, motor cars, weaving machines, pesticides *etc.*) may be expected to have failures and so the environmental and human health impacts of agbiotech will constantly be assessed but this does not imply heavy-handed regulation. No company in a litigious society would wish to face the financial consequences of failure; likewise, the marketplace will determine the need for a product, not sociopolitical panels. **1998-1999.**

Plant Biotechnology Biologists are now entering an exciting phase of research, the post-genomic era of investigating the functional analysis of genes and their direct and indirect products. Functional genomics employs a battery of approaches including (i) the creation of stable and transient-expression transgenic organisms; (ii) phage display systems, for example, searching domain repertoires; (iii) procedures for studying protein-protein interactions, particularly *via* transcriptional activation of one or several reporter genes; (iv) high-throughput gene expression profiling at the transcript level (DNA microarrays); (v) differential display; (vi) serial analysis of gene expression; (vii) protein composition, configuration and levels proteomics; (viii) gene trap methodology; and (ix) bioinformatics and computational genomics. DNA microarray analysis enables the survey of thousands of genes in parallel, and is deployed in expression monitoring, polymorphism analysis, and, to a limited extent, sequencing. Proteomics is a term that encompasses all the methods that analyse patterns of gene expression at the protein level, *i.e.* the proteome – the complete set of proteins encoded by the genome, including the set of proteins expressed both in time (*e.g.* development and disease status) and space (location). Two approaches tend to be adopted: the expression model and the cell-map model.

Regardless of the rapid advances in structural and functional genomics, proteomics and 'metabolic profiling' (the latter is a term A.M.M. Berrie, B.A. Knights, and I employed in 1972 at Glasgow University as we embarked on extensive analyses of plant extracts using combined gas chromatography – mass spectrometry; the modern jargon is 'metabolomics'), genetically modified (GM) crops and GM foods agitated politicians, pressure groups and the media, "organic" growers, and beekeepers. By the end of 1999, most supermarket chains withdrew foods containing GM ingredients. In October, the Government announced that no new GM foods would be allowed on sale in the UK before 2002. Even though biotechnology clearly encompasses R&D and products that transcend transgenic organisms and their products, the issue of GM crops and GM foods dominated biotechnology-related industrial, commercial, and public-sector research agendas in Europe generally, and the UK in particular. **1999-2000.**

GM Precautions Throughout the debate on GM crops, the production of improved or superior cultivars/varieties that have desirable input and output traits continues to present the greatest challenge to global agriculture, and figures as the prime target in international foresight programmes on agriculture and horticulture. In countries such as China, where a fifth of the world's population is dependent on just 7% of the world's cultivated land area, as well as in other

LDCs, there is no current viable alternative than to investigate the potential of transgenic crops and trust that conventional agriculture continues to perform as well as it does. Nonetheless, the theoretical risks of transgenic technology have been aired to such an extent that the EU invoked the 'precautionary principle'. On the basis that there is insufficient scientific evidence to conclude that there is no risk to consumers from transgenic crops or products derived from them, imports of certain GM crops have been prohibited, and commercial transgenic crops plantings largely brought to a halt. The fact that transgenic crops and their products pose no greater a risk to health and the environment than conventional or 'organic' agriculture has not persuaded the EU and most of the member states to adopt a more sophisticated approach to the GM public-perception issue, and put in place regulatory and monitoring systems that are trusted by the public. At the end of February 2000, Sir John Krebs closed the OECD GM-food Conference in Edinburgh, noting that current GM releases had so far shown no ill-effects on human health. Nonetheless, as new and more sophisticated GM foods come on stream, the mechanisms needed to approve these foods must be enhanced, modified, and improved. The concept of 'substantial equivalence', coined by the OECD in 1993, would have to be reviewed. **1999-2000.**

GM Crops, Food, Water, Allergens, and Risk In Hunger Site 2000 (http://www.thehungersite.com) it is reckoned that in LDCs, 24,000 people die each day from chronic malnutrition. Livestock and crop performance at a global level are grossly inadequate. With regard to food crops, the scientific targets are numerous: increased yield; better water-use efficiency; better nutrient-use efficiency; improved resistance to biotic stresses (viruses, bacteria, fungi, nematodes, insects, weeds *etc.*); improved tolerance of or resistance to abiotic stresses (temperature, salinity, aluminium toxicity, drought *etc.*); delayed senescence/ripening; enhanced quality (proteins, lipids, carbohydrates, minerals, vitamins *etc.*); improved harvestability; diminished allergens or toxins; better taste, texture and appearance; greater uniformity; and improved storage and processing qualities. Similar targets apply to non-food and dual-purpose crops, such as cotton (see Table 6., page 56). Many such non-food crops tend to be low-yielding and place heavy demands on inputs that have deleterious environmental effects. Access to freshwater, just 0.007% of all the water on earth, is the major limiting factor to crop production. In fact, agriculture accounts for 93% of global consumption of water through rainfall or irrigation. According to the World Meteorological Organization (Comprehensive Assessment of the Freshwater Resources of the World, 1977), two-thirds of the world's population could be facing water shortages by 2025.

Mention should be made of such advances as the work of I. Potrykus and P. Beyer who demonstrated in rice the incorporation of several genes simultaneously that code for β-carotene, the precursor of vitamin A, and the joint work between the University of Florida and Monsanto Inc. in incorporating the gene for glutamate dehydrogenase derived from *Chlorella sorokiniana* into wheat, leading to greatly increased soil nitrogen use efficiency. In fact, the recent achievements of the maize, rice and wheat breeding programmes have been prodigious. This gives optimism for overcoming the current annual genetic gain in cereal productivity of less than 1% per annum, subject to overcoming impediments such as market-distorting subsidies and regulations, underfunded agricultural R&D projects, malfunctioning public-private partnerships *etc.*.

A convoluted set of inter-company relationships and overlapping technologies in the agricultural genomics industry coupled with mergers, acquisitions, alliances, spin-out companies as well as intense legal activity over intellectual property ownership and rights have collectively presented an awkward face to investors, to NGOs, and to those opposed to biotechnology. Consequently, the year was one of crop biotechnology facing shrinking investments, an irony when the scientific potential has never been so great, and future food-security needs so pressing.

For the poor, and those that represent them and act on their behalf, the benefits of agricultural biotechnology require a measure of 'freedom to operate'. Given population pressures, the steady loss of cultivated land, diminishing access to freshwater, falling commodity prices, and reduced support for the publicly funded network of research bodies in MDCs and LDCs, the poor farmers in LDCs can only but contrast their lot in life with the technologically dependent rich in their own countries and elsewhere. Such is the impact of modern communications technology in raising expectations. M.S. Swaminathan has made the point that India has over 16% of the world's population, and 15% of its farm animals, but occupies only 2% of the land area and receives only 1% of its rainfall. Despite being largely illiterate, India's farmers have harnessed new technologies, saving India from mass starvation, but the scale of the demand for food is increasing remorselessly, and India needs to double food production in the next 10 years to ensure food security.

Of the various concerns – biological, social, economic, ethical, political – about agricultural biotechnology, the issue of risk and benefit comes to the fore. Do the benefits apply only to the few? What are the risks of not applying the technology? What are the known and theoretical risks of applying the technology to health and to the environment? What acceptable alternatives are there? What are the risks and benefits when the issue is driven by the publishing and broadcast media? Is it possible to insure against risks to people, property and the environment ('common goods')? What are the risks and benefits of a patenting system or UPOV system and can they be combined? What are the risks of having monopolistic suppliers of seed – public or private?

These questions must be placed alongside the analyses of the International Food Policy Research Institute (IFPRI) in *The World Food Situation : Recent Developments, Emerging Issues, and Long Term Prospects, 1997*. Increases so far in world food production have actually kept in advance of the increases in global population. Even so, the growth rate of world agriculture has declined from 3% in the 1960s to just 2% in the last decade; aggregated projections with reasonable initial and modestly optimistic assumptions indicate that the world food supply will continue to outpace world population growth at least to 2020. The *per capita* availability of food is projected to increase by about 7% between 1993 and 2020. As G.J. Persley in *Agricultural Biotechnology and the Poor* (CGIAR and the US National Academy of Sciences, 2000) points out, therein lies a paradox. Firstly, despite the increasing availability of food, currently around 0.8 billion of the global population are food-insecure, with children and women the most vulnerable to dietary deficiencies. Secondly, food insecurity is remarkably prevalent at a time when, for various reasons, global food prices are in decline. A.F. McCalla pointed out in 1998 that, in the period 1960-1990, world cereal production doubled, *per capita* food production increased by 37%, calories supplied increased by a similar amount, yet real food prices fell by almost 50%. Persley noted that the basic cause of the paradox is the linkage between poverty and food security, *i.e.* access to food depends on income, at a time when according to the 1997 report of the World Bank, World Development Indicators, more than 1.3 billion people in LDCs are classified as absolutely poor, with incomes per person of $1 a day or less, with another 2 billion people only marginally better off. In the LDCs, most of the population depend on agriculture and devote their energies and income on food.

K.M. Leisinger, in the 1999 IFPRI report *Biotechnology for Developing Country Agriculture*, and in *Agricultural Biotechnology and the Poor* mentioned above, considered ethical changes of agricultural biotechnology for LDCs, and attempted to distinguish between technology-inherent and technology-transcending risks. The former are essentially biosafety risks where they relate to health and the environment; the latter emanate from the political and social context in which the technology is used *i.e.* not risks specific to the technology but where its deployment may carry certain risks (*e.g.* reducing biodiversity, increasing poverty gaps between and within societies, adversely affecting trade).

Possible areas of concern over GM crop technology in respect of human health cover potential toxicity, carcinogenicity, food intolerances, use of antibiotic-resistance gene markers, potential allergies, and unintentional modification of nutritional value. There are no clear cases of harmful effects of authorised and released GM crops and food products derived from them, on human or livestock health. Nonetheless, as with any technology, including long-established plant breeding, any potential risk is addressed by considering any potential release on a case-by-case basis. Food allergens have exercised many in the GM debate, oftentimes quoting the well-publicised study of J.A. Nordlee, S.L. Taylor, J.A. Townsend, L.A. Thomas and R.K. Bush in 1996 (*New England Journal of Medicine* **334**, 688-692) in which a gene encoding a Brazil-nut methionine-rich seed-storage protein was introduced into soybean. It was because the protein was derived from a well-known allergenic source, and that serum and skin tests confirmed the presence of the allergen, that the development of the modified soybean was discontinued and not allowed into the marketplace. Food allergies, *i.e.* adverse immunologically mediated reactions to antigen molecules in foodstuffs, affect about 2% of adults and 4% to 6% of children, and are mainly attributed to exposure to four animal foods (eggs, fish, shellfish, milk) and four plant foods (peanuts/groundnuts, soybeans, wheat, tree nuts), but other major foodstuffs such as chicken, oriental and yellow mustard, tree and grass pollens, latex, apples *etc.* contain known allergens. The allergens are proteins or glycoproteins with an acidic isoelectric point and molecular masses in the range 10,000 to 80,000 daltons, and tend to be resistant to food processing and digestive enzymes. The concern that GM crops might specifically cause allergies is not supported by evidence. In fact, GM technology (antisense RNA) has been used by T. Matsuda, A.M. Alvarez, Y. Tadce, T.

Adachi and R. Nakamura in 1993 to reduce the expression of a major allergen found in rice. Also, very detailed studies by S.B. Lehrer and C. Reese in 1997 (*International Archives of Allergy and Immunology* **113,** 122-124) demonstrated in modified soybeans that, qualitatively and quantitatively, the transgenic high-oleate strain appeared to be allergenically the same as the parental wild-type despite the fact that the levels of several proteins were elevated. To date, there is no cause for concern about the allergenic potential for proteins introduced into foods from sources with no history of allergenicity. There is no room for complacency, however, and from the work of H.A. Simpson, S.L. Taylor, and R.L. Fuchs in 1996 (*Critical Reviews in Food Science and Nutrition*, IFBC/ILSI **36(S),** 165-186), there is now a safety-assessment multipartite decision-tree for assessing the allergenic potential of foods derived from GM crops, beginning with the characterisation of the source of the introduced gene, and assuming that genes transferred from sources known to be allergenic encode for one or more allergens unless proven otherwise. This framework for risk assessment involves assessment of introduced proteins in the context of their known history of allergenicity, similarity of their amino acid sequences to known allergens, the ability of the proteins to be digested, and their level of expression. In assessing and attempting to minimise risks, at this juncture there are no specific peculiarities of transgenic technology that do not also apply to conventional breeding. Moreover, allergy is a disease more frequent among the middle- and upper-income classes in MDCs than in the LDCs, where it is not a major factor in health and nutrition of the population.

Another contentious issue is the extent to which GM crops introduce ecological and environmental risks. R.J. Cook of Washington State University, in *Agricultural Biotechnology and the Poor*, mentioned above, observed that there is no evidence of any crop species having become invasive weeds because of plant breeding. He reinforced the fact that there are no new unique issues in the testing of GM crops, emphasising that the same protocols used to assess the environmental effects of GM plants equally apply to plants derived from conventional plant breeding – both in the past and currently. It is the product rather than the process that should be evaluated. Among the new risks envisaged and imagined outwith the normal range of sexual compatibility include the potential for spread of traits through outcrossing (gene transfer – the resultant hybrids may alter the population dynamics of species in natural habitats giving rise to 'genetic pollution'); induction of difficult-to-control weediness; the inadvertent selection of pesticide resistance in insect and nematode populations (super-pests); a reduction in biodiversity caused by weed-free monocultural systems; the creation of new pathogens through recombination of viruses or virus components (in plant viruses, genomic variation caused by remarkable levels of mutation is amplified by recombination events of great complexity, pseudo-recombination [genome segment reassortment in multipartite genomes], and acquisition of extra nucleic acid components); pleiotropic effects including formation of allergens and toxins, the inadvertent expression of genetic material from pathogens that will cause uncontrolled hypersensitive responses in susceptible species, tantamount to a 'genetic disease'; and human pathogenic microorganisms incorporating antibiotic resistance from antibiotic-resistance marker genes in the first generation of GM crop releases.

Not only are there strange concepts over 'ownership' or 'belonging' of genes to certain species, or even over what is considered to be 'conventional' breeding, there would also appear to be the erroneous view that species and ecosystems are genetically static. Gene flow occurs at various rates in all ecosystems. Virtually all agriculture and horticulture – including domestic gardening – involve the use of alien species, sometimes leading to the introduction of new pests and diseases, but most often the introduced species reaps the benefits of growing in environments lacking the depredation of the pests and diseases from their centres of origin. During the past century, thousands of new cultivars have been introduced into global agriculture and horticulture. Conventional plant breeding has reduced rather than increased (i) the tendency for crops to become weeds, (ii) the level of anti-nutritional and toxic compounds, (iii) erratic dormancy, (iv) traits harmful to non-target organisms, frequently to the point of decreasing the competitive ability and increasing the vulnerability of crops to pests and diseases, (v) variability or pleiotropy, through rigorous screening and statutory testing. In those cases where theoretical or actual gene flow occurs, the fundamental questions distil down to 'so what?' and 'how can it be controlled?' Conventional agronomic practices provide environmental risks in respect of the effects of replacing native flora and fauna with monocultures, modifying the water and nutrient states of the soil, tillage disturbance, modification of the soil microflora and microfauna by crop rotations, use of pesticides that disrupt flora and fauna, and large-scale disturbance to natural gene-flow patterns, including migratory pathways. Erosion and loss of *circa* 0.3% of global cultivated land (approximately 1.5

billion hectares) per annum caused by a combination of urban encroachment and poor agronomic practices mean that the efficiency of production on the restricted land area must be raised without further imperilling natural and semi-natural habitats, ecological refugia and dispersal corridors for flora and fauna. The very essence of good agronomic practice, with both conventional and GM crops, is to reduce risks, *e.g.* prevention of gene flow from outcrossing with wild or crop relatives by the use of herbicides, crop rotations, establishing minimum distances between crops, harvesting before flowering, or not growing the crop. Crop pests and diseases are controlled by the cultivation of resistant varieties and/or pesticides. Such measures ensure sustainability of the cropping system, and may require monitoring by independent authorities, not least in the European context where there is a sensitised public and body politic, concerns over agricultural sustainability, and realisation that a higher proportion of land is farmed in Europe than in the USA, meaning that what is deemed to be 'biodiversity' must be allowed to thrive in the farmland area, alongside and within crops. In many instances, advances in modern agricultural engineering mean that weed-infested crops can be cleaned and separated post-harvest, opening up the possibility of using diverse crop mixtures rather than monocultures. Biotechnological approaches also allow biodiversity to be monitored and quantified.

As far as technology-inherent risks are concerned, there are no demonstrable adverse effects from the cultivation and consumption of current GM crops, but precautionary biosafety guidelines and protocols for assessing risks on a case-by-case (crop-by-crop, gene-by-gene) basis are available from the OECD, UN Environment Programme, UN Industrial Development Organisation, the World Bank, and the EU, offering science-based hazard identification and risk assessments. Straightforward, non-pejorative regulatory frameworks will need to be devised with each new generation of transgenic material, with sunset clauses operating in these cases where crops and products have been demonstrated to be of very low risk.

Scientists have difficulty in addressing technology-transcending risks and ethical issues in the deployment of transgenic crops, regardless of using such terms as 'genetically improved' crops. There is no doubt that potential food-safety and environment risks have been grossly and sometimes obscenely over publicised as a vehicle to draw attention to technology-transcending and/or 'ethical' and 'moral' issues of concern, and it is interesting to compare the public treatment of mobile telephones with that given to GM crops, in respect of perceived risks, acceptability, and benefits. As in information technology and computing, the major advances in biotechnology have been driven by the private sector which requires various degrees of exclusivity, sometimes confidentiality, in order to function competitively in the marketplace. This alone raises particular challenges for public-sector bodies in MDCs and LDCs to establish constructive relationships with the private sector. **1999-2000.**

Europe and GM Crops Against a background of concerns about the spread of bovine spongiform encephalopathy (BSE) from the UK to five countries in mainland Europe (France, Germany, Portugal, Spain, and Switzerland), and its possible linkage to a new variant form of Creutzfeldt-Jakob disease (CJD), dioxin contamination of poultry in Belgium, continuing problems of *Escherichia coli* O157 and other food-poisoning microorganisms, a rapidly escalating foot and mouth disease outbreak, and a mistrust of scientists and regulators, genetically modified (GM) crops received bad – often hostile – publicity in Europe. Regardless of the proven safety of current GM crops in agriculture, their widespread cultivation outwith Europe, their potential contribution to wealth-creation and the quality of life – including their potential benefits to the environment – various non-governmental organisations (NGOs) such as Friends of the Earth and Greenpeace and other groups strongly opposed GM crop cultivation and utilisation in Europe. Demonstrations, sometimes violent, against GM foods took place, and meetings on the topic were frequently discomfited by implacably polarised views, prejudice, misinformation, inability to understand risks, and outright intolerance. Religious views on the inviolate separation of species (taxonomic taboos), attitudes on "ownership" of genes by species, ingrained suspicions about multinational corporations based in the USA, opposition to market-based capitalist economies (anti-globalisation), anti-Americanism, anti-science tendencies, unwillingness to accept expert views or the opinions and actions of regulators, and urban-based perceptions on the rôle and functioning of agriculture as a business, all acted against a change in direction to adopt GM technology even on a gene-by-gene, crop-by-crop, place-by-place basis. Indeed, the actions and publicity engendered by the anti-GM groups created concerns about GM organisms (GMOs) in countries throughout the world.

Pressure was brought to bear on governments in Europe to retard the development of GM crops, a position aided by the results of opinion polls. Retailers and food producers in Europe and especially in the UK responded by withdrawing GM products, and insisting that such products were withdrawn by suppliers from the food chain. This tactic operated in tandem with the marketing impetus given to 'organic' produce and products, but will undoubtedly create problems for those organisations when a change takes place on the grounds of quality, cost-benefit studies, and supply regularity. Herbicide-tolerant GM oilseed rape, one of the first GM crops of general release, proved to be a public-relations problem in the UK in respect of its outbreeding, gene flow induced by widespread pollen movement, and the inadvertent appearance of GM types in a purportedly conventional cultivar. Another highly publicised crop was StarLink maize, an animal-feed type with the potential to cause allergies in humans. Analysis of foodstuffs, principally taco shells, revealed StarLink contamination, some caused by cross-fertilisation with human-feed cultivars and also by inadequate segregation of grain stocks. There were estimates of the StarLink genes being detected in nearly 50% of the maize crop harvested in Iowa.

The debates in 2000 about gene flow from genetically modified (GM) plants spread beyond the EU, extending to discussions on the merits and disadvantages of gene-use restriction (terminator) technology sanctioned in August by the US Department of Agriculture (USDA), and the nutritional, environmental, and medicinal benefits of GM crops. Meanwhile, S. Padulosi of the Rome-based International Plant Genetic Resources Institute stated that of 5,300 species of food plants collected worldwide, more than 50% had but a single sample left in a seed bank, even though each species may have hundreds or even thousands of cultivars. The preservation, viability, and characterisation of many collections are neglected in most countries. It is ironic, therefore, that biotechnology will be central to the rescue of these genetic resources.

Massive investments in GM technology by companies such as Monsanto and DuPont, and by many governments in MDCs, and the utility of the technology to a wide spectrum of new industries in healthcare, nutrition, industrial feedstocks, and the environment, provided market optimism in North America, and to the mainstream international scientific community. Food safety standards in the highly litigious society of the USA, and the openness and independence in the USA of their Department of Agriculture, the Environmental Protection Agency, and the Food and Drug Administration, coupled to the credibility of their investigative media, clearly reinforced confidence in GM crops specifically, and biotechnology in general. European opposition to the technology and importation of its products represented a trade barrier that was difficult to justify scientifically and in trade terms. Perhaps the resistance to GM crops was able to blossom in an environment of poor marketing strategies, incomplete data sets for the impacts of both conventional and GM-based agriculture, ignorance of gene flow in agriculture, horticulture, and forestry, and the paucity of scientists able to present in debate their knowledge and opinions without complex jargon and concepts. By appreciating the slow incremental improvement of knowledge, recognising risks in all human activities, welcoming the heterogeneity of scientific opinion, having a high regard for peer evaluation, knowing the difficulty of generating "soundbites" without leading to over-simplification, and having the good manners to avoid personal vilification led to a marked reduction in participation in public debates by scientists. Most biotechnologically based scientists were described by pressure groups as "GM advocates", as opposed to the more correct description of scientists able to understand both "sides" of GM debates but aware of the huge potential of their studies. Understanding and appreciation of the behaviour of the public represented a challenge to scientists, and were areas of study rapidly taken up by social scientists and a growing population of ethicists. "Shaping" of views, "avoidance of unwanted outcomes", political "preferences", and dubious sampling and questionnaire processes were noted in some studies. The high-quality social science publications supported the view that the general public operated rationally and justifiably according to the information that was made available. With regard to GM crops, the introduction of tighter EU regulatory controls, overarching committees that are socially inclusive, wider consultation, and close monitoring of crops and their products post-release should give greater public reassurance, as the policy of crop-by-crop, gene-by-gene, place-by-place analysis continues, and the newer metabolic profiling, gene-flow measurement, and environmental impact technologies are introduced. Even so, neither multinational corporations nor scientists *en bloc* seemed able to deal with well-orchestrated attacks on them. **2000-2001.**

Agbiotech Agricultural biotechnology encompasses modern crop and livestock breeding and pathology, aspects of agronomy, veterinary services, propagation, remediation of agricultural wastes and slurries, restitution of agricultural land, storage and processing of agricultural products, diagnostics, nutraceuticals, functional foods, alcoholic drinks and beverages, industrial feedstocks (non-food, see *SCRI Annual Report 1999/2000* pp.46-47), horticultural and aspects of forestry biotechnology, other areas of biotechnology, and service providers. The production of pharmaceutical and related compounds by plants is a fast expanding area of great interest. A series of mergers and acquisitions in recent times has given rise to powerful multinational groups and interlinked groupings, although it is noteworthy at this juncture that many largely national supermarket and retailer chains are substantially larger than some of the more prominent multinational agbiotech companies, and effectively shape their futures. Nearly all the agbiotech companies operate using molecular-genetics-based technologies in common with other biotechnology sectors *e.g.* healthcare, such that there are overlapping IP interests. All are noted for their rapid uptake of new technologies and collaborating with universities and research institutes. It is the advent of the new bioindustries which employ sophisticated scientific, technological, and engineering concepts and processes that are giving rise to quantum leaps in the precision, accuracy, sustainability, and cost-effectiveness of many areas of human endeavour, especially agriculture, environmental protection, and healthcare. All these sectors have yet to reach their zenith. All have been damaged to varying extent by individuals and organisations opposed to various aspects of biotechnology and globalisation, as well as by media accounts of regulatory failures on the control of livestock diseases that adversely impacted on consumers and the taxpayer. Some individuals and organisations have questioned the need for agricultural biotechnology, ignoring global trends in population growth and increasing consumer demands, and the need to mitigate the environmental impacts of food production on a steadily decreasing but precious global area of cultivated and cultivatable land. By about 2020, given continued freedom from catastrophic or cataclysmic events (*e.g.* war, diseases, asteroid strike *etc.*) and modest population growth, food production capacity will revert to being a political imperative. This position contrasts with the present rapid decline in importance and the negative perception of agriculture nationally and internationally. **2000-2001.**

Plant Breeding An area of priority must be plant breeding which has an underpinning rôle in providing improved types of plant to resist the depredations of pests, diseases and adverse environments, to enhance yields, to meet ever-increasing customer demands, to provide livestock feed, and industrial non-food supplies (feedstocks). It is in essence, even using the most advanced technologies, time-consuming, spanning decades. It requires strategic planning, ranging from access to parental material, crossing programmes, to the selection stages, followed by statutory testing and marketing. For species with long juvenile (ripeness-to-flower) periods, such as many forestry hardwood and softwood species, long-term planning is essential as of now. **2000-2001.**

Plants Plants are special. They share characteristics (Table 7) that are fascinating and highly complex. Accordingly, agbiotech applications with respect to plants require specialised facilities and expertise. **2000-2001.**

IP and Agricultural Biotechnology Agbiotech is an integral part of the so-called "knowledge economy". It is dependent on integrating the skills and concepts of genomics, proteomics, metabolomics, analytical chemistry, information technology, agriculture, horticulture, forestry, and ecology. By deploying an array of fast-developing, generic technologies, it is able to address demands for food and non-food products, for both niche or mainstream markets, bringing in its wake detailed product specifications, properly monitored quality-assurance schemes, improved habitats, lowered inputs, advanced waste processing, and IP protection offering competitive advantage. Current agricultural practice (both conventional and organic) will come under greater scrutiny as its outputs, including those affecting non-monetary goods, will not be able to compete with agbiotech production in the medium-to-long term, regardless of the efforts of certain organisations, governments, or groups of nations to retard the progress of technology. In broad terms, the seven major factors suppressing the development of agricultural biotechnology at present are the weakened economic standing of agriculture and its commodities; a general downturn in technologically based investments; a much-reduced emphasis on agricultural and plant sciences in universities; food scares; the vulnerability to anti-technology pressure groups which focus on individual scientists, their organisations, companies, politicians, local and national governments; a risk-avoidance culture; and diminished public-sector investments in the sector. Perhaps the public sector should take the lead in introducing GM crops. Few investors currently consider the vast sizes of the commodity and food markets, the opportunities for wealth creation and improvement in the quality of life, and the societal needs for the products of agbiotechnology. As a consequence of these points, the market has not favoured merged agricultural, pharmaceutical, and environmental companies. **2000-2001.**

Agricultural Chemicals Closely associated with a portion of the agricultural biotechnology industry is the agrochemical industry. Collectively, the global turnover of the sector was *circa* $40 billion, and it sustained a strong R&D base. Focused on by the naïve as an unnecessary imposition on agriculture and horticulture, in reality, the use of agrochemicals was instrumental together with improved cultivars and better agricultural engineering in the agricultural revolution that enabled global food production to match the growth in the human population. As the industry developed during the 1980s and 1990s, new products with lowered environmental impacts were released as it became subject to legislative and other controls. In parallel with this, a series of mergers and acquisitions took place leading to stronger vertical and horizontal integration. By 2001, there were only seven international R&D-based agrochemical companies, three of whom were headquartered in the USA (Dow Agrosciences, Dupont, and Monsanto), and the remainder in Europe (Aventis, BASF, Bayer, and Syngenta). Further mergers were mooted. Only Syngenta – the largest of the companies in 2000 – sustains a substantial research centre in the UK, contrasting starkly with the situation three decades ago, when the UK was a major international force in the agrochemical industry, reinforced by a strong public- and private-sector R&D base. As plant biotechnology, newer forms of synthesising and analysing bioactive compounds, and bioinformatics (computational genetics) developed, it was expected that the UK with its pioneering contributions in those areas as well as in agrochemicals would reach a dominant position, extending beyond agrochemicals *per se* into the generation of improved cultivars and wholly novel plants, industrial crops and feedstocks, bioremediation, and novel products for healthcare purposes. This was not to be. Fortunately, the position is recoverable with suitable investments in the public and private sectors, new attitudes and understanding, and crucially, political support. **2000-2001.**

Cartagena Protocol *The Cartagena Protocol on Biosafety : Reconciling Trade in Biotechnology with Environment and Development* edited by C. Bail, R. Falkner, and H. Marquant, Royal Institute of International Affairs, 2002, details the background and outcome of the adoption of the Cartagena Protocol on Biosafety to the Convention on Biological Diversity (CBD) in January 2000 after nearly four years of international negotiations that were themselves founded in biosafety meetings in the early 1970s. Although the nub of the Protocol was how to protect the environment and human health from the potential danger of GMOs or Living Modified Organisms (LMOs), the negotiations were conducted without firm evidence of any environmental damage caused by the release of GMOs or LMOs, and sharp divisions over the potential risks involved. The Protocol is essentially a precautionary instrument, and emerged during intensifying politicisation of the GMO debate. Unfortunately, scientists did not play a major role in the negotiations, contrasting with the involvement of environmental and other non-governmental organisations (NGOs). There were discussions about the outcrossing of GM oilseed rape, the potential development of resistance in target insects and the potential effects on non-target organisms from the cultivation of Bt maize, the 'Pusztai' case, and a few other high-profile science-related developments.

Principle 15 of the Rio Declaration states "In order to protect the environment, the precautionary principle shall be widely applied by States according to their capabilities. Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimise such a threat". This influenced the role of the 'precautionary principle' (or properly precautionary approach) in the Cartagena Protocol (see Articles 10 and 11) but there is in Annex III, general principles, point 4 a counterbalancing statement: "Lack of scientific knowledge or scientific consensus should not necessarily be interpreted as indicating a particular level of risk, an absence of risk, or an acceptable level of risk". Importantly, the Protocol refers to 'potential adverse effects' as a precondition for possibly triggering precautionary measures. The question then arises as to the extent which the precautionary principle represents a principle or possibly a customary rule of international law. Thereafter, the WTO Agreements on Sanitary and Phytosanitary Measures (SPS), and on Technical Barriers to Trade (TBT) need to be analysed in the context of the Cartagena Protocol and trade in biotechnology products. At the present time, the WTO's case law is uncertain, and the criteria of unilateral risk assessment and risk management, taking into account also socio-economic factors, would allow for extensive trade restrictions in GMOs and LMOs. It is likely that the

WTO dispute resolution mechanisms will be under pressure. **2001-2002.**

GM Crop Debate In previous Reviews, I have dwelt at length on the debate about GM crops. The surreal situation in Europe and the UK has occupied the broadcast and printed media in sensationalist outpourings. In the absence of 'bad' actual accounts of GM crops, scare tactics have been used based exclusively on scenarios that are damaging to biodiversity and nature, human health, agriculture and horticulture, and international trade. D.L. Kershen, Earl Sneed centennial Professor of Law in the University of Oklahoma, released in 2002 a landmark article *Innovations in Biotechnology – Public Perceptions and Cultural Attitudes : An American's Viewpoint* (dkershen@ou.edu). He argues cogently that the debate about agricultural biotechnology is of equal importance as that of Galileo *versus* Ptolemy, or Darwin *versus* Lysenko, drawing on the examples of China, Europe, India, and the USA. It should be obligatory reading for European policy makers. Not unrelatedly, the reading should also extend to *In Defence of Global Capitalism* by J. Norberg (ISBN 91-7566-503-4) published in 2002. As pointed out by Gwartney and Lawson *et al.*, 2001, in *Economic Freedom of the World 2000,* the most free countries with open economies had the highest *per capita* incomes, the highest percentage growth through the 1990s, rapid technological uptake, and the lowest number of poor people as a percentage of the population based on the UN Human Poverty Index. They are also the least corrupt.

Around 14 million people in southern Africa are threatened with starvation, a figure likely to rise throughout 2002. On the eve of the UN World Summit on Sustainable Development in Johannesburg in August 2002, a major dispute erupted when the EU rejected a plea by the USA to offer reassurance to the affected southern African countries about the safety of GM emergency food relief. Mozambique, Zambia, and Zimbabwe turned back food shipments of GM grain – the USA supplies over 50% (500,000 tonnes) of the region's humanitarian aid – evidently preferring death by starvation than a theoretical risk to human health, and crop and livestock exports to the EU. Scientifically and morally, the action of the EU was reprehensible. Zambia has around 1.75 million of its population facing starvation, and suffers 20% HIV/AIDS infection rates. Its President, Levy Mwanawasa, stated that "we will rather starve than give something toxic". Zimbabwe's chaotic political situation, HIV/AIDS pandemic, and drought, means that it faces a prodigious humanitarian crisis. Three countries accepted GM maize: Lesotho, Malawi, and Swaziland. The UN World Food Programme has urged needy countries to accept the imports.

- Eukaryotic organisms based on a cellular construction. More advanced forms show the phenomenon of alternation of generations.
- Autotrophic mode of nutrition arising from the possession of intracellular chloroplasts that are responsible for photosynthesis.
- Complex carbon metabolism giving rise to a special type of squalene cyclisation and production of elaborate cell walls. Considerable cellular and metabolic heterogeneity. Living cells exhibit turgor.
- Lack of cell and organism motility: cells often joined by cytoplasmic bridges, the plasmodesmata.
- Open-ended development of modular growth habit by virtue of retaining apical and lateral meristems.
- Growth patterns subject to interacting influences of the environment with specialised detection systems and biological clocks. Light (spectral composition, intensity, temporal distribution/photoperiod), temperature (day/night and root/shoot differential requirements as well as various chilling and high-temperature requirements), gaseous composition of the atmosphere, magnetic fields, gravity, wind-speed, humidity, rainfall, edaphic (soil) factors, allelopathic and allelomediatory effects, pests, diseases, and grazing all affect growth patterns giving rise to considerable design plasticity, and modification of chemical composition.
- Unique positional signalling systems: no differentiated nervous system.
- Single parenchymatous cells able to generate whole plants (totipotency). The pattern of differentiation can be regulated by defined growth media.
- Reproductive strategies can be sexual and/or asexual, and may involve a juvenile or ripeness-to-flower period. Dormant dispersal units or structures may be produced to distribute progeny in time and space.
- Complex mass transport pathways: the xylem is dead when functional for transport of water and mineral salts: the living phloem transports the products of photosynthesis and nitrogen metabolism. Transport of solutes and growth factors may be apoplastic or symplastic.
- Cellular and physiological differentiation associated with vacuolation and susceptibility to senescence processes. No immune system.
- May have large genome sizes (*e.g. Lilium davidii,* DNA content of 43.2×10^{-12}g, per genome, and $2\chi=24$, compared with 6×10^{-12}g, $2\chi=46$, for humans. One picogram (10^{-12}g) is equivalent to 0.965×10^{9} base pairs).

Table 7 The general characteristics of plants.

Sensitivity over GM crops extends to their use as animal feeds. The major UK retailers attempt to source non-GM products but recognise that for such products as fats and oils, carbohydrates, micronutrients, and additives it is difficult to have full traceability. *Current and future GM crop market dynamics : the case of soybeans,* published by Brookes West (graham.brookes@btinternet.com), noted the rise in the demand for non-GM soybeans and warns of the possibility of price rises whilst the prices of GM soybeans and meal fall in line with its global increase in production and yield efficiency. The extra costs will either have to be transferred down the supply chain, or further pressures will be placed on the feed and livestock production sectors. A thriving market is developing for authenticity testing.

A valuable, albeit incomplete, forward look on biotechnology was produced by the Agriculture and Environmental Biotechnology Commission (AEBC) in April 2002, entitled *Looking Ahead. An AEBC Horizon Scan* (aebc.contact@dti.gsi.gov.uk). It was intended to be an internal awareness document, strongly focused on the UK, and drew on a series of consultations. Although virtually all the points raised in the consultations were relatively well-rehearsed in numerous debates and articles, including this series of *Annual Reports*, over the past six years, there was a polarisation of views, interesting because no commercial production of GM crops is permitted in the UK. Mention was made of mergers and acquisitions in the crop seed, agrochemical, pharmaceutical, and small-company biotechnology sector, such that there are now very few multinational agrochemical and seed companies (*e.g.* Syngenta, Bayer/Aventis, Monsanto, Advanta, DuPont/Pioneer, Dow, BASF) – but there was no detailed appraisal of the sharp contraction of the UK R&D effort in these areas in both the public and private sectors, a trend likely to continue for the short to medium term. Likewise, there was no audit of the UK intellectual property and competitive positions. Transboundary issues, such as product segregation, smuggling, gene flow *etc.* were considered in brief. Herbicide tolerance, pest resistance, fungal resistance, viral resistance, bacterial resistance, abiotic-stress resistance, increased yield, food-product quality, animal-feed quality, plants as factories, other non-food crops, smart plants, trees, fish, insects, other animals, bioremediation and phytoremediation were assessed fairly naïvely in terms of the aim of the work, possible benefits, possible risks, and 'further issues'. Noteworthy of comment is the way in which the AEBC volunteered itself to cover all aspects of biotechnology, including social, economic, legal, and political trends, and offer what it regards as authoritative reports. Meanwhile, as science budgets have been squeezed, an increasing proportion of R&D spend has been directed to policy issues relating to potential adverse effects of GM technology, reducing the research effort in cutting-edge innovation. Presently, the diversity of approach to GM crops throughout the world and the low level of harmonisation of regulatory processes means that the debate will continue, unresolved, for a few years yet. Many of the arguments for and against GM food are at cross-purposes; absolutes (as in virtually all areas of human activity) are rare; emotions run high; political and economic viewpoints can rarely be reconciled; rational analyses of risks, benefits, and existing technologies tend to be ignored; intolerance is rife; and some confuse research with commercialisation. The reader is recommended to consult *Genetically Modified Food and the Consumer*, edited by A. Eaglesham, S.G. Pueppke, and R.W.F. Hardy, National Agricultural Biotechnology Council Report 13, 2001. In this, an account is given of a meeting held to discuss the safety, ethical, marketing, and environmental issues that influence the acceptance of agricultural and food biotechnology by consumers. The risks of not developing biotechnology are greater than failing to develop or impeding its development without just reason. In the UK, the Prime Minister's Strategy Unit produced a Scoping Note, *The Costs and Benefits of Genetically Modified (GM) Crops*, following an announcement by the Secretary of State for the Environment, Food and Rural Affairs in May 2002 (http://www.strategy.gov.uk and GMCrops@cabinet-office.x.gsi.gov.uk). This study will run alongside a review of the scientific issues raised by GM crops and feed into a protracted debate on the potential impacts of growing GM crops in the UK. In 1998, the EU stopped approving new applications for imports of GM food, a moratorium that was only lifted in October 2002, and which was *de facto* illegal under EU law and WTO rules. No GM crops are permitted to be grown commercially in the UK, and the results of the Farm-Scale Evaluation trials, in which SCRI is involved, are eagerly awaited.

The Marketing Battle over Genetically Modified Foods by B. Wansink and J. Kim (*American Behavioral Scientist*, **44**, 1405-1417, 2001), describes current models of consumer behaviour to point out the ineffectiveness of both proponents and opponents of biotechnology in educating consumers. Their analysis of fallacious and accurate assumptions is relevant to the UK debate. **2001-2002.**

Agriculture: Past, Present and Future

Historical Perspectives: Agriculture in Britain 1700-1900 By 1700, many foods and crops were exchanged between Europe, Asia, and the Americas. In Britain, the potato, tea, coffee, chocolate, and tobacco had become commonplace, and sugar was a cheap commodity. From 1700 to 1800, there were fundamental societal changes and turmoil, including the Union of England and Scotland on May 1 1707 and adoption of the Union Jack; the incorporation of the South Sea Company (1711); the Treaty of Utrecht (1713); the 'Fifteen' Jacobite rising in Scotland (1715-1716); the war with Spain (War of Jenkin's Ear; 1739-1748); War of the Austrian Succession (1740-1748); the Second Jacobite Rebellion (1745-1746); adoption of the Gregorian calendar (1752; "Give us back our eleven days" – the days between September 2 and September 14 were omitted); land and naval war between Britain and France (1756-1763); the Treaty of Paris (1763); the resignation of Lord North for failing to subdue the American colonies (1782); and the War of American Independence (1775-1783). At the beginning of 1801, the legislative union of Great Britain and Ireland was enacted, under the name of the United Kingdom.

The Eighteenth Century is thought by many historians to represent artistically the shift from the Classical to the Romantic ages, but more importantly it was the initiator of the Industrial Revolution and the Agricultural Revolution. Robert Burns died in 1796, by which time there had been a war with Revolutionary France for three years. Science and technology had already made great strides, *e.g.* John Tuberville Needham (1713-1781) in *Observations upon the Generation, Composition, and Decomposition of Animal and Vegetable Substances*, published in 1748, reported that boiled, sealed flasks of broth teemed with 'little animals', but Lazzaro Spallanzani (1729-1799) devised a properly controlled experiment to test such factors as the amount of heat needed to kill contaminating microorganisms. In 1749, George Leclerc, the Compte de Buffon (1707-1788) published the 54-volume *Histoire naturelle*, focusing on the main elements of evolutionary biology sustained up to the beginning of the 20th century – geographical distribution, development, isolation, transmutation, correlation, and variation of organisms. In the tenth edition of *Systema naturae*, published in 1758, Carl Linnaeus (1707-1778) catalogued all the then-known flora and fauna, including humans, consistently using a binomial nomenclature, thereby laying the basis of modern taxonomy. Agriculture had been advanced by the publication in 1732 of Jethro Tull's (1674-1741) *New Horse Hoeing Husbandry* describing his inventions and introductions, such as the seed drill (1701), the horse-hoe, and soil pulverisation. Robert Bakewell (1725-1795) introduced selective breeding of livestock. Charles Townshend (1674-1738) introduced crops such as turnips and clover for winter fodder. These early pioneers, whose efforts were publicised by Arthur Young (1741-1820), produced the Agricultural Revolution that led to fundamental changes globally in the production of foodstuffs and animal materials such as wool and hides. By 1801, Franz Achard (1753-1821) built the first sugar-beet factory in Silesia, enabling the sugar beet industry to develop in France and Germany. In 1834, Cyrus H. McCormick (1809-1884) patented his reaper. Plough technology was developed by Jethro Wood (1774-1834) with the cast-iron plough in 1819; John Lane in 1833 with the steel-bladed ploughshare; John Deere (1804-1886) introduced the steel plough in 1837; the chilled plough of 1855 by James Oliver (1823-1908) was improved in 1857 by the Marsh brothers; cable ploughing was introduced in 1850 to be followed by the steam plough by John Fowler in 1858. The revolving disc harrow was introduced in 1847, the binder in 1850, two-horse straddle-row cultivator in 1856, combine harvester in 1860, combine seed drill in 1867, and the sheaf-binding harvester in 1878. Pasteurisation as a preservation technique for beer, wine, and milk was introduced in 1861 after the pioneering work of Louis Pasteur (1822-1895). Chemical fertilisers came into widespread use in the 1880s following the pioneering research at Rothamsted by J.B. Lawes. Mechanical freezing, long-distance rail travel, internal-combustion-engined tractors were introduced in the latter half of the 19th century. Between 1850 and 1900, about 200 million hectares of grazing land in the USA were converted into grain fields; similar conversions to arable land took place in Australia, Russia, and several countries in South America.

In the first part of the 19th century in the UK, the ending of the Napoleonic wars was associated with economic depression, and as a form of remedial action, the Corn Law of 1815 was introduced to protect agricultural landlords from imported grain until home-grown corn reached the 'famine price' of 80 shillings a quarter. Bread prices rose and there was widespread malcontentment. In the 1820s, William Huskisson, the then President of the Board of Trade, breached the protectionist mercantile system by reducing duties in several imports (*e.g.* coffee, sugar, cottons, woollens, silk, iron *etc.*). In 1828, the Corn Law was modified to permit grain to be imported at any time and fixing duties on a sliding scale. Parliamentary reform characterised the period 1830-1846, introducing important social developments (abolition of slavery in the colonies, the Factory Act, growth of trade-unionism, new Poor Law *etc.*). In 1845-1846, there was considerable agitation against the Corn Law, fostered by Richard Cobden and John Bright, political leaders of the Manchester School, building on the Manchester Anti-Corn Law Association (1838) and Anti-Corn Law League (1839). The ruin of the Irish potato crop and the threat of famine were instrumental in gaining the support of Robert Peel, leading in turn to the Repeal of the Corn Laws on June 6 1846. By June 29 1846, the government led by Peel was overthrown by a parliamentary revolt led by Benjamin Disraeli. In 1879, there was a severe agricultural depression arising from the worst harvest of the century, a period associated with a general economic downturn, several strikes, the unpopular Afghan and Zulu wars, and problems with Ireland. The remainder of the 19th century, like the rest of the century, was marked by growing internationalisation of trade, and scientific and technological achievement.

UK agriculture was transformed with enclosure (inclosure) of 'waste' and common land. During 1702 to 1802, 577 Acts were passed for enclosing over 8 million acres of such land. *The First Report from the Select Committee of The Honourable The House of Commons Appointed to take into Consideration the Means of promoting the Cultivation and Improvement of the Waste, Uninclosed, and Unproductive Lands of the Kingdom*, 1 January 1796 (price one shilling and replete with the long s(*f*)!) resolved that "the cultivation and improvement of the waste lands and commons of the Kingdom is one of the most important objects to which the attention of Parliament can possible be directed, and that the granting of a bounty to encourage the cultivation of potatoes, in lands at present lying waste, uncultivated or unproductive, would not only be the means of augmenting, in a considerable degree, that valuable article of food, but might also be the means of promoting the improvement of extensive tracts of land, at present of little value". The Select Committee also opined that "certain legal liabilities that stand in the way of division and enclosure of waste lands should be removed". Reference was made to the idea of lands in common was "derived from that barbarous state of society, when men were strangers to any higher occupation than those of hunters or shepherds, or had only just tasted the advantages to be reaped from the cultivation of the earth". "Those who live in the neighbourhood of great wastes are still an idle and lawless set of people", "that such commons are the frequent resort of thieves and other depredators on the public", "and are on that account but particularly near the capital, a public nuisance". The Bishop of Llandaff stated "That whilst there is an acre of such waste improveable land in Great Britain, it may be hoped that when the Legislature shall turn its attention to the subject, no inhabitant of this island will be driven, by distress, to seek a subsistence in Africa or America". The report estimated that there were 7,888,777 acres of uncultivated land in England and 14,218,224 acres in Scotland giving a total of 22,107,001 acres of waste land, compared with 39,027,156 cultivated acres in England, and 12,151,471 acres in Scotland. The uncultivated area was regarded as a great source of future national wealth. **2001-2002.**

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 northeast 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 sites 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 for 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 fields, 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 Matthias 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 (1916-2004) 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, phthalimides, 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 been 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 is 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. **2002-2003.**

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, (j) the inability of organic farming methods to meet increasing demands on global food supplies without encroachment on natural habitats, (k) the high cost of production compared with conventional and agbiotech systems, and (l) 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. 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 coexist 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 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 mean 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. **2002-2003.**

Tourism Rural tourism interdigitates with agriculture and horticulture. It is reliant on the visual amenity and other free benefits, as well as paid benefits, provided by these underpinning primary industries. Only when large-scale deleterious changes in the landscape take place, or when travel restrictions are introduced following pest and disease outbreaks – amplified by ghastly media reports as in the UK's 2001 foot and mouth disease outbreak – is this dependence revealed. The UN International Labour Organisation estimated that in 2000 the tourism industry as a whole employed 207 million people, equivalent to 8% of global employment. According to the World Tourism Organisation, international tourism expenditure in 2000 was *circa* \$65 billion in the USA, \$46 billion in Germany, \$35 billion in the UK, \$32 billion in Japan, \$16 billion in France, \$156 billion in Italy, and \$11 billion in Canada and the Netherlands. International tourist arrivals were 75 million in France, 50 million in the USA, 48 million in Spain, 41 million in Italy, 30 million in China, 25 million in the UK, and around 20 million in Russia, Mexico, and Canada. **2000-2001.**

Future of Agriculture In a supplementary and on-going survey complementary to the UK Technology Foresight and Foresight exercises, I have sought the views of leading-edge successful agriculturalists in Australia, Canada, France, Germany, South Africa, Spain, UK, and the USA. Over four years it has been remarkable to see a relative unanimity of views that point to the main needs of agriculture. For crops, breeding is regarded as a pivotal requirement, with access to improved cultivars for pest and disease enhanced resistance, enhanced quality and longer seasons. Automation, involving precision systems, decision-support systems, and robotics are seen to bring huge benefits in cost-effectiveness. Sustainability relating to profitability is of increasing importance in respect of water- and nutrient-use efficiency, fewer pesticides and soil remediation. Biotechnology is seen very positively as the primary process to deliver breeding systems, new products and markets, health and disease control, and new opportunities. Animal welfare activism seemed to be a peculiarly British phenomenon. Concern is expressed about accessing new technologies and markets and how to achieve on-farm added value, but there is the realisation that family farms are under pressure as agricultural and horticultural industrialisation is underway, and vertical and horizontal integration of agriculture and other related industries takes place. In due course, I shall publish the survey.

Simply put, modern-day agriculture, if allowed to flourish as a proper business, will allow crops and livestock to be grown where they produce the most efficient yields. Huge post-harvest losses suffered in the LDCs will be largely eliminated. Herbicides, pesticides, chemical fertilisers, new varieties, and automation, collectively were responsible for the tripling of global crop yields between 1960 and 1992 on more or less the same area of cultivated land (*circa* 1.56 billion hectares). Without agricultural improvement, an additional 2.87 billion hectares would have been needed, all derived from natural ecosystems. Thus, the natural habitats have been protected. Our new challenge is to improve yields on existing land to meet a doubling of the present global population in 47 years, if current population trends are to continue. The challenge may be too modestly presented were the populations of LDCs to demand a diet rich in animal products as in MDCs. **2000-2001**

Future of Agricultural Research Funding for agricultural research has diminished as rapidly as the population grows. The International Food Policy Research Institute estimated that global spending on relevant research was only \$15 billion to support a multi-trillion-dollar food industry. Over the last 30 years, cuts of around 30%-65% have been made in public spending on agricultural research in the MDCs. Farm subsidies and trade barriers, however, have risen enormously. Biotechnology and new-generation agrochemicals are now revolutionising agriculture and preserving biodiversity. Pesticides have not yet caused the extinction of a single known species, despite their use over 50 years. A crisp and pithily accurate review of agriculture entitled *Saving the Planet with Pesticides, Biotechnology and European Farm Reform* by Dennis

Avery was presented as the 24th Bawden Lecture at the 1997 Brighton Conference organised by the British Crop Protection Council. **1998-1999.**

Future of International Agriculture Over the next five years, agriculture is likely to remain under massive price pressures in order to meet the demands of urban populations and politicians for cheap and wholesome food, all-year-round, regardless of the weather. Food prices globally have progressively declined in real terms. Irrespective of the generic nature of the science, engineering, and technology used in the life and environmental sciences, agricultural innovation is likely to be one of the casualties of these pressures, as profitability and investment decline. Agriculture is essentially a private-sector activity – it has been badly affected in the past by regulation, intervention by heavy layers of bureaucracy, taxation, subsidy, and an underlying willingness of certain states to become almost a monopoly supplier – collectivisation has led to starvation. A stagnation of agricultural R&D is a potential disaster as governments have become complacent on the back of technology-dependent agricultural successes, forgetting the vagaries of the weather and the adaptability of pests and diseases. In *Agriculture and rural extension worldwide. Options for institutional reform in the developing countries,* FAO, Rome, 2001, agricultural extension systems in various countries are now described as failing, moribund, in disarray, or barely functioning. Access to water, water-use efficiency, and nutrient-use efficiency by crops, and cultivar performance are huge issues. Numerous studies have shown that agricultural improvement reduces poverty and inequality. In Africa, agriculture employs around 66% of the labour force, and accounts for 37% of GNP and around 50% of exports (*World Development Report 2000,* World Bank, Washington DC). N. Nagarajan in *The Millennium Round: An economic appraisal* (European Commission Economic Papers, European Commission, Brussels) estimated that developing country gains from a 50% cut in tariffs, by both MDCs and LDCs, would be in the order of $150 billion, about three times the aid given to LDCs. The CGIAR Centers are under pressure. Even international genebanks and germplasm collections are suffering from declining funding – according to FAO, there are about 6 million samples of plants held in around 1,300 repositories, many of which in the LDCs may be lost, despite the worldwide commitment to safeguard biodiversity. I urge policyholders in the UK and elsewhere to consult *Global Food Projections to 2020. Emerging Trends and Alternative Futures* by M.W. Rosegrant, M.S. Paisner, S. Meijer, and J. Witcover, International Food Policy Research Institute, August 2001. As P. Pinstrup-Andersen points out, there is one inescapable conclusion: "even rather small changes in agricultural and development policies and investments, made in both developed and developing countries, can have wide-ranging effects on the number of poor and undernourished people around the world. The policy choices we make now will determine to a considerable degree what kind of lives the next generation will lead". **2001-2002.**

UK Agricultural Policy Another particular pressure in the UK is the policy environment surrounding agriculture and the countryside, with the involvement of a wide range of stakeholders, some holding irreconcilable differences. Agriculture in the UK remains in the doldrums and faces further harsh times. Industries related to agriculture, such as plant breeding and agricultural chemicals are also under stress. Many companies are disinvesting from the UK, and their associated R&D activities terminated. There is talk of a 'post-agricultural' countryside such that farming is but one of several participants and often regarded as a recipient of rural social therapy (*i.e.* public funding) to maintain 'environmental goods'. New thinking is required. For farming, it is eminently possible to produce new crops and types of livestock; new ways of helping to provide the lungs, kidneys, visual amenity, and recreational base for the urban masses, as well as the usual supply of food and non-food products. Most important, agriculture can be, should be, and must be, a successful business. A UK agricultural roadmap should be synthesised. Allied to the decline in UK agriculture is a decline in plant science (botany). From a position of pre-eminence in numerous universities, institutes, and companies, botany has diminished rapidly in national importance. It is in the scientific and economic interest of the UK that the situation is rectified. **2001-2002.**

OECD The Organisation for Economic Co-operation and Development (OECD) came into force in 1960 with the aim of promoting (a) policies designed 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. **2002-2003.**

Food Chain 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 its commercial arm, Mylnefield Research Services Ltd. **2002-2003.**

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 gauge 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. http://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 rain-water 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. **2002-2003.**

Medicinal Plants The world has embarked on the 'knowledge economy', a new educational and social phenomenon, raising the question as to the part to be played by countries that are not in the select group of 'leading' economies. There is a danger that many countries will become increasingly sidelined from the benefits to be obtained from exploiting modern science, engineering, and a raft of new technologies. Consolidations, mergers, and strategic alliances are altering national and transnational trading arrangements. Huge flows of capital take place across borders, flows that dwarf the roles of bodies such as the World Bank and International Monetary Fund. The growing influence of such bodies as the World Trade Organisation demonstrate the inexorable rise of globalisation and international competition. The Internet is revolutionising the flow of information, scholarship, and the methods of trading. Importantly, intellectual property (IP) is tradable. There are huge opportunities arising from new areas of science, principally in information technology, computing, physics, chemistry, and biotechnology. Advances in molecular genetics have given rise to a plethora of new industries based on structural and functional genomics, proteomics, metabolomics, bioinformatics, diagnostics *etc.* which are collectively referred to as the 'modern bioindustries'. A noteworthy development has been the formation of 'industry clusters' which comprise co-located universities, institutes, spin-out companies, service-providers, stockists, marketing and design companies, and related manufacturing companies.

Drugs from plants represents an expanding area of human endeavour with widespread ramifications into public health policy, new approaches for pharmaceutical industries, the application of state-of-the-art technologies and manufacturing systems, novel intellectual property, access to traditional knowledge, exploitation of terrestrial and aquatic biodiversity, and policy issues on benefit-sharing.

In *Webster's Third New International Dictionary* (Merriam-Webster Inc. 1980), 'drug' is defined as (a) a substance used as a medicine, or for making medicines for internal or external use; (b) a substance recognised in an official pharmacopoeia or formulary; and (c) a substance used for the diagnosis, cure, mitigation, treatment, or prevention of disease. Drugs, therefore, include diagnostics and prophylactics. Biotechnology refers to the use of organisms, parts of organisms, or living processes for the needs of humans, an activity that is the most R&D-intensive industry in most of the advanced economies.

Medicinal plants have and continue to be used directly or processed to (a) soothe and cure infections, diseases, and pain; (b) sedate, arouse, and hallucinate; (c) act as birth-control agents, purgatives and blood-pressure regulators; (d) control excretions and secretions. There is debate as to the extent to which modern medicine is based on drugs from plants consequent on the impact of synthetic chemistry. In the *United States Pharmacopoeia*, 70% of the listed drugs were plant-derived whereas by 1936, 40% were plant-derived, a figure that has remained more or less constant, although several of the remaining 60% are conceptually based on plant-derived remedies. In addition, there is a rapidly growing over-the-counter market in nutritional supplements, most of which relate to traditional herbal medicines, and regulatory authorities worldwide are attempting to bring in quality-assurance measures, and seek validation of health-enhancing claims.

In this 'post-genomic era', there is renewed interest in medicinal plants, as the pharmaceutical multinationals seek new approaches to generate new products, and governments become concerned over the massive growth in healthcare costs. As it is, around 80% of the global population is dependent on herbal medicine, based on traditional knowledge gleaned through generations of trial-and-error observations, word-of-mouth descriptions, and various types of record-keeping.

Written records extend back to the Sumerian, Assyrian, Babylonian, Egyptian (*e.g.* the *Ebers papyrus* that details 850 plant medicines), Indian (*e.g. Rig Veda* that details 1500 plant medicines) and Chinese (*e.g.* Shen No(u)ng, the Yellow Emperor, Taoists) civilisations. The Greeks were influential (*e.g.* Crateuas, the *Historia Plantarum* of Theophrastus, Hippocrates, the *De Materia Medica* of P. Dioscorides), as were the Romans (*e.g.* Galenus). The Arabs were, and remain, influential in herbal medicine (*e.g.* the *Kitab al-Qanum* of Ibn u Sina, also known as Avicenna). European herbalism drew heavily on the ancient records. Collectively, *The Leech Book of Bald*, a 10th Century Anglo-Saxon account; the teachings of the Medicinal School in Salerno, Italy, beginning in the 10th Century; the concept of the Doctrine of Signatures whereby the outward appearance of plants were thought to indicate the ailments and body parts or organs they would cure, a doctrine espoused by Paracelsus (1530s) and G. della Porta (1588) and several German herbals (*e.g.* K. von Megenberg *Buch der Natur* (1475), O. Brunfels *Herbarium Vivae Eicones* (1530), L. Fuchs *De Historia Stirpium* (1542), H. Bock *Neu Kreuterbuch*, (1539), V. Cordus *Dispensatorium* (1546), (the latter being regarded as the first pharmacopoeia) were highly influential. There were several English herbals that built on the German herbals and records from elsewhere, notably R. Ban(c)ke *Herbal* (1525), P. Traveris *The Grete Herball* (1539), W. Turner *Newe Herball* (1551-1562), J. Gerard *The Herball or Generall Historie of Plantes* (1597), J. Parkinson *Theatrum Botanicum: The Theatre of Plants. Or, an Herball of a Large Extent* (1640), and N. Culpepper *A Physicall Directory* (1647).

A long phase of disagreements over interpretations of the use of medicinal plants, involved at various times, the religious authorities, 'herb wives', apothecaries, physicians, and alchemists. From about 1600 onwards, there was increasing influence of medicinal plants and medical practices from South America, North America, and the East Indies. Order was brought to plant descriptions and identities by C. Linnaeus in 1753 whose binominal nomenclature system became universally accepted, giving rise to the *International Code of Botanical Nomenclature*. Even so, herbal medicine has been abused by false claims, notably in money-making schemes during the period 1800-1900.

A combination of scientific curiosity and evolving chemical knowledge led to the isolation of bioactive compounds from plants, starting with the isolation of morphine by F. Serturner in 1830, followed over the years by a series of other alkaloids such as aconitine, emitine, atropine, quinine *etc*. The synthesis in Germany of salicin (1852) and its more patient-friendly form of acetylsalicylic acid (1899) pioneered the era of the synthetic chemist, replacing plant sources with synthetic drugs.

Conventional drug treatments have not replaced traditional medicinal meals using fresh, cooked, preserved, or processed medicinal plants. These include the therapeutic foods described by Galenus (species designated as hot, dry, damp, cold *etc*.), the Ayurvedic tastes (sweet, sour, salty, pungent, bitter, astringent), and the Yin and Yang balance of Chinese medicine (five flavours, five temperatures, and the relationship to particular organs and acupuncture meridians).

Until recent times, there remained a strong connection between the teaching of botany and medicine in the major universities, a linkage weakened with the rise of synthetic drugs and lessened interest in dietary components, although there remains interest in poisonous plants in both human and veterinary medicine. Most recently, interest in the relationship between diets and health has re-emphasised the value of plant studies, aided by exciting new discoveries in ethnobotany and ethnopharmacology, zoopharmacognosy, pharmacogenomics, nutrigenomics, plant genomics, proteomics, metabolic profiling, biosystematics, gene prospecting, bioinformatics, and studies on the physiology of secondary products.

- Infusions and teas
- Decoctions
- Tinctures
- Syrups
- Infused oils for external use
- Creams
- Ointments
- Powders and capsules
- Compresses
- Poultices
- Massage oils
- Creams and ointments from infused oils
- Volatiles and scents
- Salves
- Steam inhalants
- 'Non-alcoholic' tinctures
- Specified tincture ratios
- Fluid extracts
- Tonic wines
- Macerations
- Chinese decoctions
- Lotions
- Pessaries and suppositories
- Juices
- Herb combinations

Table 8 Preparations used in traditional approaches in herbal medicine.

Traditional approaches in herbal medicine are based on preparations of flowers, buds, shoots, leaves, seeds, roots, fruit, bark, bulbs, saps, and resins gathered and used in either dried or fresh form (Table 8).

Complementary therapies include homeopathy (which includes the concepts of infinite dilutions and placebo effects), the flower remedies espoused by Dr Bach, Japanese medicine with its origins in Shintoism and mythology, and Tibetan medicines based on Bon and Tibetan Buddhism. Many have warned of the relatively few scientifically proven complementary therapies.

The scale of the challenge facing those seeking to discover new plant-derived medicines can be comprehended by the fact that less than 5% of the *circa* 250,000 species of Angiosperms have been investigated for medicinal purposes. Other plant groups (Gymnosperms, Pteridophytes, Bryophytes, Lichens, Algae, Fungi, Bacteria *etc.*) are largely unexplored in their various terrestrial, freshwater, and marine environments, their very biodiversity raising the probability of massive chemical diversity and novelty, reflecting the full panoply of the autotrophic habit of plants. In addition to various types of preparation (involving sample processing, storage, and extraction), sampling protocols need to take into account: (a) different phases of growth (from the seed to senescent adult material), (b) different parts of the plant, (c) cultivation – the plant is often grown under widely diverse environmental conditions (soil, atmospheric composition, temperature, daylength, light quality and quantity *etc.*), (d) frequently the plant has latent or overt infections and diseases (viruses, bacteria, fungi, insects, mites, nematodes *etc.*) – historically such material could be dangerously poisonous, but now infected material can be used to source novel materials, and finally, (e) identity – care has to be taken with regard to inadvertent hybridisation and gene flow.

High-throughput screening has attracted massive investments. Possible chemical structures range from 10^{18} to 10^{200} (an average of 10^{60}), according to R. Bohacek (*Med. Res. Rev.* **16**, 3050, 1996). Guidance as to target molecules has come from a variety of sources. Examples include the work of M. Hann and T.I. Oprea (*Curr. Op. in Chem. Biol.* June 2004) in a survey of the global collection of *circa* 120 million chemical compounds which when paired with all realistic medical targets would indicate a need for the expenditure of more than $32 billion over 8 years, involving 3352 Gigabytes of information prior to entry into clinical trials. Suggested target molecules include those of molecular mass greater than 500 daltons, with high lipophilicity (cLog P>5), more than five hydrogen-bond donors, and more than 10 hydrogen-bond acceptors; to those with molecular masses of around 300 daltons, lipophilicity of equal to or less than three, the number of rotatable bonds less than or equal to three, and the polar surface area less than or equal to 60. Irrespective of the massive investments in combinatorial chemistry, genomics, proteomics, and bioinformatics, high-throughput screening has not yet resulted in a wave of new drugs. Indeed, the major international pharmaceutical companies are currently suffering a declining economic and drug-discovery performance (*e.g.* cost *per* patent), reflecting (a) a 'kill-by-numbers' expensive R&D strategy; (b) complex of 'no win – no fee' and class actions in the courts; (c) harsh attention from the media; (d) convoluted regulatory controls that increasingly demand supplementary and substantial clinical trials at short notice; and (e) a view held by many members of the public, the body politic, and public-sector research staff that the pharmaceutical industry should act philanthropically.

Huge advancements in molecular biology software have enabled the integration of desktop and web analyses. These include sequence searches; gel utilities; the display, manipulation, and editing of sequences; translation and ORF identification tools, phylogeny analyses, alignment tools, restriction enzyme and general sequencing and genomics tools, PCR amplification and analysis; proteomics and microarray tools; plasmid mapping *etc.* Some integrated biology software sites are listed in Table 9.

There are well-defined stages in isolating drugs from plants. These are extraction using organic and non-organic solvents and solubilisers, followed by separation and purification using partitioning and various types of chromatography. If the identity of the molecule under investigation is known, then internal standards can be used to optimise the extraction, separation, and purification phases. Inadvertent com-

www.invitrogen.com	Invitrogen
www.softberry.com	SoftBerry
www.ocimumbio.com	Ocimum Biosolutions
www.labvelocity.com	LabVelocity (Jellyfish)
www.dnaster.com	DNAStar
www.accelrys.com	Accelrys
www.miraibio.com	MiraiBio

[see also not-for-profit JEMBOSS – European Molecular Biology Open Software Suite]

Table 9 Integrated biology software sites.

pound degradation may be retarded by the use of antioxidants, extractions in the dark *etc.*. Identification of the compound of interest is often carried out in tandem with separatory technologies and methods of quantification, essentially to acquire the necessary bits of information to identify the compound unequivocally. Relevant techniques include GC-MS, LC-MS, MALDI-TOF, MS-MS, NMR, CD/ORD, X-ray crystallography *etc.*, in addition to various diagnostic techniques using monoclonal antibodies and recombinant antibodies. Thereafter, essential stages include (a) scaling up (bulking) of preparations, (b) safeguarding any intellectual property such as by secrecy agreements or patenting, (c) ensuring proper quality-assurance systems usually through internationally recognised accreditation schemes, followed by (d) the exquisite complexity and cost of clinical trials. Registration and marketing then ensue, raising supply-chain management issues. Clearly, modern molecular-biology tools such as customised high-density DNA microarrays, cDNA clones, ESTs, SNPs *etc.* have their utility in characterising materials and modes of action. Usually, pre-clinical trials will require whole-animal or tissue-culture techniques. Animal-rights activists have severely retarded the deployment of animal-testing facilities in some western countries, often arguing that the models have limited predictive value. Transgenic mice have particular merit, although other cheaper screening models are extensively used (*e.g.* nematodes, fruit flies, brine shrimps, zebrafish *etc.*).

At a time when, according to the World Health Organisation, around 85% of the global population depends on traditional botanical cures, it is in the interest of all responsible governments to promote the health of the people they represent. The current rising trend of healthcare costs as a proportion of national economies is not sustainable. Plant-derived diets and medicines are of pivotal importance in addressing the health of nations. There are risks from (a) misidentification of plants and/or their active ingredients; (b) contamination (*e.g.* mycotoxins, adulteration, high levels of antinutritional compounds such as glycoalkaloids *etc.*); (c) incorrect dosages, the development of drug dependence or habituation; (c) synergistic, additive, or negative interactions with other treatments. Due regard must be given to ownership and access, and special reference should be given to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). To avoid overcollection of rare species, regional conservation controls may need to be introduced, and hence the importance of *in situ* and *ex situ* genebanks and germplasm collections – expensive as they are to maintain – will increase. Far-sighted politicians recognise the need for refugia and sanctuaries for rare species. Underpinning the development of medicinal plants is the need for high-quality state-of-the-art natural-product chemistry, a topic in sad decline in most advanced economies. Even so, for those that access and exploit traditional knowledge, there is a need to identify those individuals, organisations, groups, and societies that have generated and sustain that traditional knowledge. Greater clarity is needed in the raft of rapidly evolving international agreements that relate to this area.

The huge international interest in dietary-supplements, natural cures, traditional medicine, functional foods (nutraceuticals), low-glycaemic-index products, and the bioefficiency of antioxidants and free-radical scavengers has relevance to less-developed countries as an important component of enhancing the health of the populations, alleviating poverty, and exploiting intellectual property.

Future developments include (a) robots, automation, and miniaturisation; (b) improved supply-chain management, accompanied by vertical and horizontal integration of supplies, processors, manufacturing production plants, and retailers; (c) sterile mass propagation of medicinal plants, akin to fermentation systems; haploid cultures will promote gene expression; (d) rapid breeding and selection systems in order to remove unwanted allergens and toxins as well as modify or enhance active ingredient and nutrient levels. Marker-assisted selection in association with diagnostic agents will facilitate breeding and selection; (e) transgenic and related technologies such as gene-use restriction technologies, homologous allelic recombination technologies will be essential for product improvement; (f) gene shuffling and plant viral vectors for transient expression will assume a great role in generating patient-specific vaccines and other high-value products; (g) once the active ingredients have been identified and their syntheses elucidated, then fermentation technologies will displace to a large extent the need for normal horticultural and agricultural production; (h) in turn, agriculture and horticulture will need to explore new markets *e.g.* industrial feedstocks, in addition to the supply of foodstuffs and ornamentals.

In conclusion, medicinal plants represent a rich source of novelty, new applications, and drug-discovery targets. Traditional knowledge and the latest forms of science, engineering, and technology offer a logical way forward for humanity. **2004.**

Final Statement

At a time when the future of the research organisations sponsored by the Scottish Executive Environment and Rural Affairs Department is under review (see *Strategic Research for SEERAD. Environment, Biology and Agriculture. 2005-2010.* Scottish Executive, Edinburgh 2005), it is timely for me to reproduce two key documents relating to our progenitor body, the Scottish Station for Research in Plant-Breeding. The first is the *Memorandum* published in November 1918, and the second a pamphlet published in April 1921 seeking financial contributions. Readers are also recommended to consult the article by Derek A. Perry entitled *SCRI: an historical perspective* in the SCRI *Annual Report 1994* pp 23-29.

Finally, I wish my successor, Professor Peter J. Gregory, currently Pro-Vice Chancellor of the University of Reading, every success in sustaining the growth of SCRI, Mylnefield Research Services (MRS) Ltd, Biomathematics & Statistics Scotland (BioSS), The Mylnefield Trust, and the Scottish Society for Crop Research (SSCR). I also thank colleagues, past and present, on the staff and our Governing Body, and in sister institutes, universities, colleges, and industry bodies for their outstanding efforts and support.

Memorandum

REGARDING

Scottish Station for Research in Plant-Breeding

1918

GENERAL COMMITTEE.

Highland and Agricultural Society.

Charles Douglas, D.Sc., C.B., of Auchlochan, Lesmahagow.
Dr David Wilson of Carbeth, Killearn.
Alexander Cross of Knockdon, 19 Hope Street, Glasgow.
James Elder, Athelstaneford Mains, Drem.
Sir Archibald Buchan Hepburn of Smeaton, Bart., Letham, Haddington.
Lord Forteviot, Dupplin Castle, Perth.
J. T. M'Laren, The Leuchold, Dalmeny.
John C. Robertson, Fodderty, Dingwall.
John M'Caig of Belmont, Stranraer.
G. B. Shields, Dolphingstone, Tranent.

Scottish Chamber of Agriculture.

H. W. B. Crawford, Chapmanton, Castle-Douglas.
G. A. Ferguson, Surradale, Elgin.
G. G. Mercer, Southfield, Dalkeith.
Sir James Campbell, LL.D., 14 Douglas Crescent, Edinburgh.
James Rodger, Keir Estates Office, Dunblane.
John Henderson, Annandale Estates Office, Moffat.
Isaac Connell, S.S.C., 18 Duke Street, Edinburgh.
John Findlay, Springhill, Baillieston.
David Ferrie of Parbroath, Cupar-Fife.
James Esslemont, Little Barras, Stonehaven.

National Farmers' Union of Scotland.

W. Donald, Fardalehill, Kilmarnock.
James Gardner, South Hillington, Cardonald, Glasgow.
W. J. Dudgeon, Crakaig, Loth, Sutherlandshire.
Major D. A. Spence, Dunninald Mains, Montrose.
James Gardiner, Dargill, Crieff.
W. W. Hope, The Knowes, Prestonkirk.
J. P. Ross Taylor, Mungo's Walls, Duns.
W. C. Jack, Robiesland, Lanark.
J. Picken, Torrs, Kirkcudbright.
J. Knox Ledingham, Fintry, Turriff, Aberdeenshire.

The Scottish Seed Trade Association.

David Bell, 15 Coburg Street, Leith.
William Cuthbertson, V.M.H. (Messrs Dobbie & Co.), Edinburgh.
W. P. Maltman (Messrs Alexander Cross & Sons, Ltd.), Hope Street, Glasgow.
Thomas Thomson (Messrs John Donaldson & Co.), 24 St Giles Street, Edinburgh.
Thomas Allison (Messrs George Bruce & Co.), 14 Regent Quay, Aberdeen.
James W. Drummond (Messrs W. Drummond & Sons, Ltd.), Stirling.
A. N. Hunter (Messrs Austin & M'Aslan), 89 Mitchell Street, Glasgow.
R. V. Mather (Messrs Laing & Mather), Kelso.
Tom H. Young (Andrew Riddell & Co.), 5 Grassmarket, Edinburgh.
Ian C. Menzies, 22 Rutland Street, Edinburgh.

The Glasgow and West of Scotland Potato Trade Association.

A. B. Fulton, 118 Queen Street, Glasgow.

Edinburgh and East of Scotland Potato Trade Association.

D. L. Bowe (Messrs J. H. Bowe & Sons), Dunbar.

Perth, Fife, Forfar, and North of Scotland Potato Trade Association.

Robert P. M'Lagan, 36 Caledonian Road, Perth.

Edinburgh and Leith Mill-Masters' Association.

Thomas W. Tod (Messrs A. & R. Tod, Ltd.), Leith Flour Mills, Leith.

Ayrshire and West of Scotland Wholesale Ryegrass Machiners' Association.

J. F. M'Gill (Messrs M'Gill & Smith, Ltd.), 69 Kyle Street, Ayr.

National Association of Corn and Agricultural Merchants.

Edinburgh Area.

James Grant (Messrs John Grant & Sons, Ltd.), Dundee.

West of Scotland Area.

Robert Dickie (Messrs J. & W. Wallace), 498 Gallowgate, Glasgow.

Berwick-on-Tweed Area.

Philip Wilson, Grain Merchant, Duns.

Aberdeen Area.

A. T. M'Robert (Aberdeen Lime Co.), Aberdeen.

Co-opted Members.

Dr R. B. Greig, 29 St Andrew Square, Edinburgh.
J. Milne Home, Irvine House, Canonbie.
Harry Hope, M.P., Barneyhill, Dunbar.
The Marquis of Linlithgow, Hopetoun House, South Queensferry.
Lord Lovat, C.B., D.S.O., &c., Beaufort Castle, Beauly.
Sir Hugh Shaw Stewart, Bart., C.B., of Greenock and Blackhall, Ardgowan, Greenock.
Brig.-General Stirling of Keir, M.P., Dunblane.

Executive Committee.

Charles Douglas, D.Sc., C.B., of Auchlochan, Lesmahagow.
David Bell, 15 Coburg Street, Leith.
D. L. Bowe (Messrs J. H. Bowe & Sons), Dunbar.
Alexander Cross of Knockdon, 19 Hope Street, Glasgow.
James Elder, Athelstaneford Mains, Drem.
James Gardner, South Hillington, Cardonald, Glasgow.
G. G. Mercer, Southfield, Dalkeith.
J. F. M'Gill (Messrs M'Gill & Smith, Ltd.), 69 Kyle Street, Ayr.
J. T. M'Laren, The Leuchold, Dalmeny.
Dr David Wilson of Carbeth, Killearn.
Dr R. B. Greig, Board of Agriculture for Scotland (*co-opted*).

Chairman—

CHARLES DOUGLAS, D.Sc., C.B., of Auchlochan, Lesmahagow.

Secretary—

JOHN STIRTON, 3 George IV. Bridge, Edinburgh.

Scottish Station for Research in Plant-Breeding.

Historical.

THE Directors of the Highland and Agricultural Society of Scotland decided, in June 1917, to approach the Board of Agriculture for Scotland with regard to the establishment of—

(*a*) a station for the testing and registering of agricultural seeds and plants, and

(*b*) a station for research in plant-breeding.

A Sub-Committee was appointed, which subsequently had two Meetings with the Board of Agriculture.

The Committee was cordially and sympathetically received by the Board, and after full consideration and discussion it was found that the Board were in agreement with the Committee that the time had come when steps should be taken for the proper testing and registering of new seeds and plants and the granting of certificates to the raisers of these. Prompt action by the Board of Agriculture followed these Meetings. At their instance the Secretary for Scotland authorised the necessary expenditure and the acquisition of a farm, so that the institution of a seed-testing and registering station promises, at an early date, to become an accomplished fact.

The proposal for the establishment of a station for research was also sympathetically received by the Board, although circumstances incidental to the state of war appeared to preclude their taking immediate action. The Directors of the Highland and Agricultural Society felt, however, that the matter was of such urgency, and of so great importance to the Agriculture of Scotland, that further delay was undesirable.

Conference regarding the Proposed Station.

On 25th June 1918 they decided to invite representatives of the Scottish Chamber of Agriculture, the National Farmers' Union of Scotland, and the Scottish Seed Trade Association, to a Conference with the object of promoting the scheme for the establishment of such a station, and, if so agreed, appointing a Committee which should have charge of details, confer with the Board of Agriculture, and co-operate in raising the necessary funds. They also decided to recommend that the Society give a grant of £2000 towards the object, which grant was unanimously agreed to at a Special General Meeting of the Society on 26th July.

At the Conference, which was held on 26th July 1918, and presided over by the Right Honourable Robert Munro, K.C., M.P., Secretary for Scotland, it was unanimously resolved to approve the proposal to create in Scotland a station for research in plant-breeding, and to commend it to the support of the Board of Agriculture for Scotland and all interested in the industry of Agriculture. The Secretary for Scotland, in commending the scheme to the Meeting, stated that he proposed to sanction the expenditure from public funds towards the funds required for the station, of pound for pound of the amount raised by voluntary effort, up to a reasonable limit.

Appointment of Committee.

It was further resolved that a Committee be formed to confer with the Board of Agriculture regarding the establishment of the proposed station, and to take the necessary steps to obtain public support; and that this Committee consist of ten members appointed by the Directors of the Highland and Agricultural Society, ten appointed by the Directors of the Scottish Chamber of Agriculture, ten by the Central Executive of the National Farmers' Union of Scotland, ten by the Executive Committee of the Scottish Seed Trade Association, and one from each of the following: The Glasgow and West of Scotland Potato Trade Association; The Edinburgh and East of Scotland Potato Trade Association; The Perth, Fife, Forfar, and North of Scotland Potato Trade Association; The Edinburgh and Leith Mill-Masters' Association; The Ayrshire and West of Scotland Wholesale Ryegrass Machiners' Association; and the National Association of Corn and Agricultural Merchants; the Committee to have power to co-opt additional members.

The National Association of Corn and Agricultural Merchants was subsequently given a representation of four members, being one from each of its four Scottish areas. The names of the members of the Committee, including co-opted members, are given on pages 1-4 of this booklet.

The Proposed Station.

What is proposed is to establish a thoroughly equipped Station for the improvement of agricultural plants, by selection and by the creation of new varieties possessing in the highest degree those qualities which will make them most profitable under Scottish conditions.

Value of Improved Seed.

The importance of this aim hardly needs demonstration. It is an agricultural commonplace that no single factor in production has more influence than the selection of the best and most suitable seeds and plants; and improvement of these does not merely add to but actually multiplies the effect of all other favourable conditions. Cultivation and manuring, essential as they are, depend for their effect on the selection of plants capable of responding profitably to their influence.

What is perhaps less generally and fully realised is the degree in which the economic value of plants is capable of being increased. Much has been done—and nowhere more than in this country—to effect this by private effort. But the chief lesson of experience is that every result that is attained makes possible some further improvement, so that no limit can be set to the progress that may eventually be made.

Moreover there is not sufficient inducement for the individual to undertake certain lines of research which are most important from a National point of view. Even if the improvement aimed at were obtained, it would not repay to him the outlay for long continued and highly skilled work.

New Methods in Plant-Breeding.

The possibilities of progress have been enlarged, and its direction has been defined, through the rediscovery in recent times of the Mendelian methods. It is now an established fact that by inter-breeding and selection it is often possible to combine in one new variety of plant desirable characters which at present belong only to separate varieties, and which may even have been thought inconsistent with each other.

The possession of this new method, enlarging as it does the possibilities of progress, and making clear the lines along which definite results are to be sought, opens up a sphere of action too large and too vitally important to be left to be occupied only by the separate efforts of private investigators. Plant-breeding has become an enterprise at once so definite in its character, and of such vital moment to Agriculture, that it demands the continuous and disinterested support which can only be obtained by making it a public charge.

The value of plant-breeding, and more particularly of the method to which reference has been made, is not a matter now of mere forecast or conjecture. Even in its most definite economic or business aspect, it has already been demonstrated beyond dispute by the successes that have been attained, more particularly in the famous Swedish Institution at Svalöf, and in a more restricted way at Cambridge.

Some Notable Achievements.

It is not necessary to multiply instances of successful results; but even those to whom scientific research makes, on its own account, least appeal, will recognise the great practical value—the large contribution to production—which attaches to the creation of such plants as the so-called Extra Squarehead wheat, bred at Svalöf, to combine the hardiness and the ability to resist rust of one of its parents with the stiffer straw and higher yield of the other, or of the Little Joss, bred by Professor Biffen at Cambridge, which yields similar admirable results in England. Of more immediate interest to the majority of Scottish farmers is such an achievement as the Victory Oat of Svalöf, which combines so many of the valuable qualities of the varieties from which it was bred.

Problems peculiar to Scotland.

Such problems as the production of an earlier ripening variety of oats are of great importance under Scottish conditions, but it may not, indeed, be in the cereal crops at all that we shall derive most immediate benefit. Certainly our root crops and our pastures are matters that concern us no less than our corn-fields. Potato raising and growing, especially for seed, has become an industry of national importance. All alike present a wealth of problems as important economically as they are scientifically abstruse.

In this connection reference may be made to the Continental methods which have more than trebled the percentage of sugar in sugar-beet, and to the recent successful use of wild white clover seed in this country. We are led to hope that the feeding quality of turnips and swedes may ultimately be greatly increased by somewhat similar methods of breeding; and the seeds of local indigenous species of some grasses and other plants may be developed and prove more permanently productive in Scottish pastures than our present commercial counterparts.

Importance of National Scheme.

It would, indeed, be foolish to prophesy precisely in what directions or to what extent plant-breeding may be made to contribute to the productiveness of our National Agriculture; but it cannot be doubted, in presence of the results attained elsewhere, that it must in the end contribute largely and steadily; and while we have profited, and shall in the future continue to profit, by the results of investigations made in other countries, it is no less abundantly evident that what we have to gain from research in our own country must greatly surpass what we can hope to derive from the most valuable investigations made elsewhere. We have our own special crops and our own still more special conditions of soil and climate. It is to these that researches must be directed if they are to produce the fullest practical result for us.

In whatever directions research may proceed, it is not only a matter of national self-respect, but of the most direct practical importance, that the researches on which we are to depend should be native to our own country—that the problems to be investigated and the conditions under which they are to be studied should be those that are relevant to us.

Not only so, but if Scotland is to retain the prominent position hitherto enjoyed as a seed-producing and exporting country, it is of paramount importance that research work of the nature proposed should be begun. The soil and climate of Scotland are conducive to hardiness and vigour of constitution, and if the stocks produced are of the best and purest, an increased demand from other parts of the United Kingdom and elsewhere may, in the future, be looked for. The financial value of this demand to the Agricultural industry and the country generally would be considerable.

Administration.

It has already been said that the development of plant-breeding is now too large an interest to be left any longer only to private initiative. The problem of the future is to unite the freedom of the investigator with the combination of efforts that is required in order to produce large and continuous results; for while of all forms of effort none is more individual in its character than the work of scientific research, none stands to gain more by the stability which can be achieved through combined action. Now this union of personal independence with public support can best be attained in an Institution adequately endowed, and governed by those who are, on the one hand, practically interested in the results that are sought, and, on the other hand, prepared to view in a patient and sympathetic way the efforts that are made to secure results which are often remote and difficult. It is self-evident that such a Station as is now proposed ought to be in close contact with the Board of Agriculture, since administration and research mutually influence each other; and it is no less evident that the establishment and endowment of the Station are proper objects for the expenditure of public money. It is therefore most satisfactory to have the assurance of the Secretary for Scotland that, up to a reasonable limit, he is prepared to furnish from public funds a sum equivalent to that which may be obtained from other sources. Such support, as a matter of course, entitles the Board of Agriculture to have a voice in the management of the Station; and this would in any case be desirable. But it is generally agreed that an Institution which is to carry out free scientific research, and to devote itself to the solution of agricultural problems, ought not to be a mere appendage of a public department, but must be independent in its government and be controlled by those to whom the scientific and practical problems of Agriculture are a matter of vital and direct concern. In order to secure this object, the proposed Station must have an income independent of any help it may receive from public funds, and the larger that income the more complete will be its opportunity of free development.

Distribution of Produce.

It will eventually be necessary to make provision for the distribution of the produce of the Station; and it is essential that this should be done in such a way as not to compete or interfere with, but rather to utilise the ordinary trade channels.

Finance.

While it is estimated that the cost of purchasing and equipping a suitable farm and buildings need not exceed £20,000, the annual charges of a vigorously conducted plant-breeding station, directed by the best expert obtainable, cannot fail to be heavy, and it is desired to assure an annual income of not less than from three to four thousand pounds. This income should be derived, not from annual subscriptions, in themselves uncertain and always liable to be discouraged by any temporary failure to produce definite results, but by means of an endowment fund; and it is the aim of the Committee to raise not merely half the cost of purchase and equipment, but also a capital sum the income from which will be sufficient to meet half of the annual outlays, the other half in both cases coming from Government funds. The amount it is hoped to collect from private sources is, therefore, from £40,000 to £50,000. The Committee are encouraged to believe that in making this attempt they have the practical and enthusiastic support of the great body of Scottish farmers, as well as of the members of the Seed and Allied trades. To that support they make their chief appeal. But they venture also to bespeak the help of those who, while not directly concerned with agriculture, realise its vital character as a national interest, and the great issues that are involved in its future prosperity and vigour.

November 1918.

Subscriptions Intimated.

The following subscriptions have been intimated:—

	£	s.	d.
Highland and Agricultural Society of Scotland	£2000	0	0
David Bell, 15 Coburg Street, Leith	1000	0	0
Alex. Cross & Sons, Ltd., 19 Hope Street, Glasgow, per Alexander Cross	1000	0	0
M'Gill & Smith, Limited, 69 Kyle Street, Ayr	1000	0	0
William Dods & Son, 44 Court Street, Haddington	250	0	0
P. Lawson & Son, Ltd., Edinburgh	250	0	0
Roughhead & Park, Ltd., High Street, Haddington	250	0	0
David Wilson, D.Sc., of Carbeth, Killearn	250	0	0
D. L. Bowe (J. H. Bowe & Sons), Dunbar	250	0	0
Dobbie & Co., Edinburgh	150	0	0
Lord Forteviot, Dupplin Castle, Perth	100	0	0
Charles Douglas, D.Sc., C.B., of Auchlochan, Lesmahagow	100	0	0
Sir Hugh Shaw Stewart, C.B., of Greenock and Blackhall, Bart.	100	0	0
George Barclay, Thornhill, Johnstone	100	0	0
W. J. Campbell Sibster, Edinburgh	100	0	0
Duncan M. Wallace (John Wallace & Sons), Paton Street, Glasgow	100	0	0
Edinburgh and Leith Millmasters' Association	100	0	0
Laing & Mather, Seedsmen, Kelso	100	0	0
John Wallace & Sons, Paton Street, Glasgow	100	0	0
Daniel Wyllie & Co., 197 High Street, Ayr	100	0	0
Thomas Dow & Co., 239 High Street, Ayr	100	0	0
John C. Robertson, Fodderty, Dingwall	50	0	0
John Grant & Sons, Ltd., Dundee	50	0	0
Harry Hope, M.P., Barneyhill, Dunbar	50	0	0
James W. Scarlett, J.P., Sweethope, Inveresk	50	0	0
Major Spence, Dunninald Mains, Montrose	50	0	0
Lord Glenconner, The Glen, Innerleithen	25	0	0
Colonel Charles Brook of Kinmount, Annan	25	0	0
George M. Maclennan, Springfield, Inveresk	25	0	0
United East Lothian Agricultural Society, Haddington	25	0	0
Dalkeith Agricultural Society	25	0	0
James Gardner, South Hillington, Cardonald, Glasgow	25	0	0
Alexander Murdoch, East Hallside, Newton	25	0	0
John Inglis & Sons, Bonnington, Leith	21	0	0
Thomas Elder of Stevenson, Haddington	21	0	0
George Bertram Shields, Dolphingstone, Tranent	21	0	0
Thomas Kirk of Abbey Mains, Haddington	21	0	0
A. and W. Douglas, Dalkeith	20	0	0
John H. Deans, Pitcox, Dunbar	20	0	0
Dr R. B. Greig, 29 St Andrew Square, Edinburgh	20	0	0
W. W. Hope, The Knowes, Prestonkirk	20	0	0
H. W. B. Crawford, Chapmanton, Castle-Douglas	20	0	0
George A. Ferguson, Surradale, Elgin	20	0	0
Thomas Harper, Fordel, Dalkeith	20	0	0
Ian C. Menzies, 22 Rutland Street, Edinburgh	20	0	0
William J. Reid, Fordhouse of Dun, Montrose	20	0	0
J. P. Ross Taylor, Mungo's Walls, Duns	20	0	0
Anonymous, per James Elder, Athelstaneford Mains	15	0	0
Andrew Motherwell, Limited, Gorbals Grain Mills, Glasgow	10	10	0
F. M. and G. Batchelor, Craigie Home Farm, Dundee	10	10	0
Isaac Connell, 18 Duke Street, Edinburgh	10	10	0
Robert Smith & Sons, Mid-Calder	10	10	0
John Stewart, Struthers, Cupar-Fife	10	0	0
Phipps O. Turnbull, Smeaton, Dalkeith	10	0	0
William Donald, Fardalehill, Kilmarnock	10	0	0
J. W. Adamson, Easter Inch, Bathgate	10	0	0
James Wilson, Westburn, Cambuslang	10	0	0
James Kinloch, Tullichewan Home Farm, Alexandria	10	0	0
Carry forward	£8326	0	0

Brought forward	£8326	0	0
R. D. Thom of Pitlochie, Gateside, Fife	10	0	0
John Henderson, Annandale Estates Office, Moffat	10	0	0
John M. Rodger, Balgone, St Andrews	10	0	0
John Stodart, Adniston, Macmerry	10	0	0
Mrs Douglas, Mayfield, Dalkeith	10	0	0
George G. Mercer, J.P., Southfield, Dalkeith	10	0	0
Charles Stodart, Kingston, North Berwick	10	0	0
David Ferrie, of Parbroath, Cupar-Fife	10	0	0
Jos. G. Scott, Congalton, Drem	10	0	0
J. W. Millar, Lochhead, East Wemyss	10	0	0
James Campbell, LL.D., 14 Douglas Crescent, Edinburgh	10	0	0
John P. Alison, D'Arcy, Dalkeith	5	0	0
James Adam, Abbotsinch, Paisley	5	0	0
Peter Robertson, Home Farm, Dalmuir	5	0	0
James Lennox, Redhills, Crieff	5	0	0
John Findlay, Springhill, Baillieston	5	0	0
J. D. Cameron, Kirkton, Golspie	5	0	0
James Clark, Gospetry, Milnathort	5	0	0
W. J. Dudgeon, Crakaig, Loth	5	0	0
Alexander B. Stevens, Mains of Kilgraston, Bridge of Earn	5	0	0
J. L. Paterson, Quhytewollen, Lockerbie	5	0	0
John Speir, Newton, Cambuslang	5	0	0
Wm. C. Jack, Robiesland, Lanark	5	0	0
Alexander Smith, Cranley, Meikleour	5	0	0
John Gibb, Gladstone, Bishopton	5	0	0
Matthew Snodgrass, Old Mains, Inchinnan	5	0	0
John Hunter & Son, Edinburgh	5	0	0
George MacLellan, Redheugh, Gorebridge	5	0	0
R. S. White, Halkerston, Gorebridge	5	0	0
Melville Neill, Keilling, Keils, Lochgilphead	5	0	0
A. M'Pherson, Braes of Greenock, Callander	5	0	0
James Cadzow, Kilpunt, Broxburn	5	0	0
Anonymous, per Jas. Elder, Athelstaneford Mains	5	0	0
Subscriptions under £5	7	4	0
	£8553	4	0

Scottish Station for Research in Plant-Breeding.

I desire to {intimate / enclose} a donation of

....*Stg.* (£.......)

to the fund being raised for the establishment of a Scottish Station for Research in Plant-Breeding.

Signature...

Postal Address...

....

Date...........................

NOTE.—This intimation or remittance may be sent to the Secretary of the General Committee (Mr John Stirton, 3 George IV. Bridge, Edinburgh), to the Secretary of any of the Organisations, mentioned on pages 1-3 of this booklet with which the subscriber may be connected, or to the Secretary of any local Agricultural Society which may be receiving subscriptions

Scottish Society for Research in Plant-Breeding.

THE Society is registered as a Specially Authorised Society under the Friendly Societies Act, 1896. A list of Trustees, Directors, and officials appears on page 4 hereof.

Objects.

The objects of the Society, as defined in its Constitution, are the promotion of Agriculture, Aboriculture and Horticulture, by means of experimental and other research for the improvement of plants and crops in Scotland, and the investigation of conditions affecting their production.

The immediate aim of the Society is the establishment of a thoroughly equipped Station for the improvement of agricultural plants, by selection and by the creation of new varieties possessing in the highest degree those qualities which will make them most profitable under Scottish conditions.

Site of Station.

An excellent site for the Station has been secured at East Craigs, Corstorphine, within four miles of Edinburgh. This consists of about 35 acres of good land, with commodious dwelling-house, garden, greenhouse, cottages, and other buildings.

Entry to the ground was obtained in November of last year, but by an arrangement with the tenant of East Craigs the Society obtained possession of 3 acres of ground in the spring of 1920. Through the kindness of the Board of Agriculture for Scotland the Society was fortunate enough to receive the whole of the experimental stock of Cereals and Potatoes belonging to the late Dr Wilson of St Andrews. The propagation of these stocks, and the experimental work which Dr Wilson had in progress, were continued last year at East Craigs, under the charge of Mr William Robb, N.D.A., who was for several years Dr Wilson's Assistant, and whose services have been secured by the Society. A comprehensive collection of foreign Oats and Barley was also secured and grown in plots at the Station. It will thus be seen that the Society has already a valuable collection of seeds to form the basis of the research work which it hopes to carry out.

Director of Research.

The Research work at the Station will be under the direction of Mr Montagu Drummond, B.A., F.L.S., Craigs House, Corstorphine, formerly Lecturer in Plant Physiology in the University of Glasgow.

Funds.

The funds of the Society consist of voluntary subscriptions and donations, amounting at 31st December 1920 to £22,245. To this falls to be added an equivalent grant from the Government of £22,245 (which will be increased to £22,500 when the voluntary fund reaches that figure), giving a total of approximately £44,490. From this there has to be deducted the cost of the site, and other expenses to date, amounting to £8630, leaving a capital of approximately £35,860. It will thus be seen that further financial support, in the shape of donations and members' subscriptions, is urgently required if the work of the station is not to be seriously hampered.

Membership.

All interested in Agriculture, Aboriculture, or Horticulture, are eligible for membership of the Society, and will be admitted on the following conditions:—

(a) *Life-Membership.*—Donors of £20 or over, including donations to the preliminary fund.

(b) *Annual Membership.*—
- (1) Donors of £10 or over, who pay an annual subscription of 10s.;
- (2) Persons paying an annual subscription of £1.

The annual subscriptions are payable on 1st April each year.

The Directors of the Society earnestly appeal to all interested in the important work of Research in Plant-Breeding to support this national institution by becoming members of the Society.

April 1921.

SCOTTISH SOCIETY FOR RESEARCH IN PLANT-BREEDING.

DIRECTORATE.

The ever-changing global environment: not a reason for complacency

J.A. Raven*

Politicians, scientists and the news media have much to say about current changes in our environment, and especially on climate change. This contribution considers current environmental change in the context of past changes in the Earth's environment, and current views of this change in relation to the changing scientific perceptions of how the Earth's environment has changed in the past.

Evolution and revolution in geological and biological thought. Starting in the eighteenth century, developments in the natural sciences led to the development of a 'Uniformitarian' view of the history of the Earth, and of the methods by which this history should be studied, in contrast to the cluster of views that were termed 'Catastrophism'. These terms were coined by Whewell in 1832, and crystallised the views of Lyell, who interpreted past events by studying present-day events, and of the contrasting perceptions of Cuvier and Sedgwick among others who believed that the geological changes revealed by stratigraphy occur by processes which are not happening today, e.g. diluvialism which attributed many phenomena observed in geology to the biblical flood [1]. A part of catastrophism is directionalism, whereby the Earth's components have undergone a directional change [1]. This was especially seen in the fossil record of animals 'ending' (for the moment) with *Homo sapiens.* It must be emphasised that both of these views allow for change with time in the Earth's surface and its fossil components, i.e. are evolutionary in the sense of change with time.

Lamarck, and Darwin and Wallace, accepted biological evolution, i.e. change with descent as opposed to origin (creation) without subsequent change, but differed in the mechanism involved. The Darwin-Wallace perception of evolution by natural selection of heritable variation, as opposed the Lamarckian inheritance of characters which changed in direct response to environmental challenges, is, of course, the current view [2]. The uniformitarian versus catastrophist views of Earth history have echoes in the recent controversies over the punctuated equilibrium as opposed to the gradualist view of evolution by natural selection [2]. Regardless of the extent of a relatively constant rate of change as opposed to episodic changes during biological evolution, it is clear that there were major extinction events at intervals throughout the last 650 million years for which the fossil record is adequate to yield evidence of the extent of biological diversity. Thus, regardless of the time course (gradual, or by punctuated equilibrium) of change in lineages of organisms through the time between mass extinctions, the mass extinctions represent 'catastrophes' which can be broadly contrasted with essentially uniformitarian changes in the intervening periods following evolutionary radiation after the extinction event [2].

The causes of these mass extinctions is a matter of current debate, as indeed is what qualifies as a mass extinction, and thus how many such events there have been since the fossils in the stratigraphical record became adequate to record them. Five major extinction events have been recognised at or near the end of the Ordovician, Devonian, Permian, Triassic and Cretaceous epochs at, respectively, 443, 354, 248, 206 and 65 million years ago. These mass extinctions involved the loss of at least 65% of species, and they have been related to major environmental changes on Earth, such as large-scale vulcanism, or a meteorite impact, both of which have been suggested as a cause of the end-Cretaceous mass extinction which included the demise of dinosaurs. Weaker, because less mechanistically plausible, arguments for the causes of these Phanerozoic mass extinctions have involved changes in climate and in sea level [2].

One process which must have had a major effect on biota was the gradual oxygenation of the Earth which occurred starting about 2,300 million years ago[3,4]. This build-up of oxygen was not contemporaneous with the evolution of oxygen-producing photosynthesis in cyanobacteria, since there were inorganic reductants which consumed the oxygen which would otherwise accumulate when the organic carbon produced in parallel with the oxygen was buried rather than re-oxidised in respiration.

When these inorganic reductants had been exhausted, oxygen built up locally in the surface ocean and the atmosphere and only subsequently in the deep ocean [4-6]. This 'oxygen revolution' had a major influence on biota. Before oxygen build-up began the organisms had not been exposed to oxygen, and the interaction of oxygen with redox reactions yields toxic, mutagenic, oxygen radicals. The main source of these oxy-

*Plant Research Unit, University of Dundee at SCRI.

gen radicals in cells before the advent of free oxygen was the photochemical influence of ultraviolet radiation. More significantly, ultraviolet radiation is absorbed by, and damages (chemically changes) informational macromolecules. While oxygenation increased the potential for damage by oxygen free radicals, the photochemical (involving ultraviolet radiation) production of ozone in the stratosphere forms an ultraviolet-absorbing shield which limits the ultraviolet flux to the surface of the ocean and to the land surface, and this restricts ultraviolet damage to cells. Oxygenation thus had very great effects on the potential for damage to informational macromolecules, increasing effects from oxygen free radicals but reducing damage from ultraviolet radiation.

Oxygen also had a very important effect on biota by providing an electron acceptor for respiration which permits the greatest quantity of useful energy to be obtained from oxidation of a given substrate molecule. The increased oxygen level, and increased oxygen:carbon dioxide ratio, in the atmosphere and much of the rest of the surface biosphere impacts negatively on the primary productivity of photosynthetic organisms via effects of the core carboxylation enzyme ribulose bisphosphate carboxylase-oxygenase. Other biological influences of oxygen include a decrease, by oxidation to the less soluble ferric form, in the availability of iron, and hence of phosphorus by the binding of phosphate to ferric iron compounds; these effects are probably major feedback controls, via changes in primary productivity, on the oxygen content of the biosphere. These examples show that oxygenation of the biosphere had a very great biological impact. The fossil record does not permit quantitation of the impact on speciation and extinction, but it was probably of a magnitude which compares with the subsequent 'big five' extinctions [4].

Returning to changes in our understanding of the age of the Earth and changes in its environment over the last century and a half, the age of the Earth was deduced to be less than 100 million years in the nineteenth century on the assumption that the Earth had been steadily cooling since it formed as a molten body, with heat, ultimately derived from gravitational energy, transmitted radially within the Earth purely by conduction. The discovery of radioactivity and its decay at the end of the nineteenth century gave another significant source of heat for the Earth, and also permitted radiometric dating showing that the Earth is some 4.5 billion years old [2]. Radioactive heating is also now known to be the ultimate driving force for plate tectonics, suggested by Wegener in the early twentieth century on the basis of a wide range of lines of evidence as continental drift, but without an obvious mechanism [2].

Another consideration is the temperature at the Earth's surface, which is a essentially a result of the temperature needed for black body radiation by which long-wavelength radiation dissipates energy from the Earth's surface at the same rate as that at which it arrives as short-wave radiation from the sun. In the early nineteenth century Fourier, and Tyndall, pointed out that polyatomic (more than two atoms) atmospheric gases, such as water vapour and carbon dioxide, absorb radiation in the wavelength range of the black body radiation from the Earth, and are important in maintaining the Earth surface temperature higher than that if there were no such 'greenhouse gases' [7]. At the end of that century Arrhenius made accurate calculations of the extent of this greenhouse effect, and it is now known that the Earth's mean surface temperature of 288 K would only be 256 K in the absence of 'greenhouse gases' [2].

The role of the greenhouse effect in maintaining the Earth's surface in the temperature range at which liquid water could occur continuously over the last 3.8 billion years was further emphasised when it became known that the sun has increased its output of electromagnetic energy by more than 20% over that time. There must have been a decrease in the greenhouse effect over time to account for the known Earth surface temperatures over the last 3.8 billion years. The surface temperature of the Earth is also controlled by its albedo, a function of cloudiness and ice cover. Ice cover is in part dependent on the extent of heat transfer from the tropics to poles, which is in part a function of the distribution of land and sea as a result of plate tectonics in the long-term Wilson cycle. Over most of the last 3.8 billion years we now know that the Earth spent more of its time in a hot-house state, with little or no ice, rather than in an ice-house state[2].

Another very significant insight into the control of surface temperature of the Earth's surface came from Milankovich. His work involved mathematical analysis of the changes in eccentricity of the Earth's orbit, the changes in obliquity (the inclination of the axis of the Earth's rotation to the plane of the orbit), and the precession of the equinoxes. These astronomical phenomena alter the solar radiation reaching the Earth, and their periodicities of about 96,000 years (eccentricity), 41,000 years (obliquity) and 21,000 (precession) have been related to changes in aggregate ice volume in the recent (Pleistocene) glacial-interglacial cycles [2]. There is also the likelihood that these periodicities have influenced climate over much longer time periods.

The atmospheric gas composition, dust deposition and surface temperatures have been determined for the last 420,000 years, including the last four glacial episodes, by analysis of the Vostok ice core in Antarctica [8]. Temperature and dust deposition, with temporally restricted atmospheric gas composition, data are available for the last 740,000 years for the Dome C ice core [9]. These analyses have shown that the glacial periods have lower atmospheric levels of the greenhouse gases carbon dioxide, nitrous oxide and methane than the warmer interglacial periods. More recent work has demonstrated a greater parallelism of the temperature changes and the greenhouse gas changes than was found in earlier analyses [10]. The available time resolution does not show whether the greenhouse gases change before, in precise parallel with, or after, the change in temperature. Even if the greenhouse gas changes do precede the temperature changes, a reason for the greenhouse gas changes must be sought if they are to be considered as at least a partial cause for the temperature changes.

One suggestion is that the increased atmospheric dust content, as also recorded in the Vostok ice core, in glacial episodes increased carbon dioxide drawdown from the atmosphere into the surface ocean through greater primary productivity and sedimentation of the resulting organic carbon. An increase in marine primary productivity, which is supported by some but by no means all independent evidence from the natural abundance of stable isotopes in marine sediments [11], is proposed to have been caused by iron in the dust which relieved the constraints on primary productivity in the high nutrient, low chlorophyll areas with low pigment content (biomass of primary producers) and primary production, yet relatively high nitrate and phosphate concentrations. Today the largest of these regions is the Southern Ocean. There are still doubts about this suggestion. Regardless of a causal effect of changes in greenhouse gas concentrations in producing temperature changes, the greenhouse gas changes could amplify changes in temperature as a result of, for example, changes in solar energy input via the Milankovic cycles [8,9].

These environmental changes, and especially the Pleistocene glaciations and the cooling which preceded them following the Late Palaeocene Thermal Maximum, have had profound influences on biodiversity, biogeography and biogeochemical cycles. However, as far as global speciation and extinction are concerned the Pleistocene did not have major influence until the last 50,000 years or so when human influences are probably at least partly responsible for, as an example, the loss of many large, and other slowly-reproducing, mammals from cooler parts of the world [12-14].

These considerations show that there have been very great environmental changes in the past which gave rise to mass extinctions and subsequent evolutionary radiation. The question that we now address is whether we are currently in the sixth, anthropogenically induced, mass extinction event if there have already been five (the Big Five) mass extinctions [15].

Present and Future Environmental Change: Impact on Biota. It is generally believed that there has been a significant increase in the temperature at the Earth's surface over at least the last century. The atmospheric concentration of the greenhouse gases carbon dioxide, methane and nitrous oxide has increased at an accelerating rate since about 1750, in parallel with increasing industrialisation and changed land use [16]. In the last few decades increases in these three naturally occurring greenhouse gases have been paralleled by increases in the purely anthropogenic chlorofluorocarbons [16]. A causal relationship between the increased concentration of greenhouse gases and the increase in the mean global temperature is logically defensible and is much more likely to be true than not [17,18]. However, there are feedback mechanisms which could counter, or amplify, the effect of increased greenhouse gas concentrations on global temperatures [16]. The possibility of such effects has led some policy-makers, especially in the United States, to use such uncertainties to delay action which could mitigate warming.

One argument which can be used to minimize the role of the increased 'permanent gases' in the atmosphere is the complexity of the hydrological cycle which controls the amount of water in the atmosphere. Water is the most quantitatively significant of the greenhouse gases, and accounts for about two-thirds of the present greenhouse effect of the atmosphere. The hydrological cycle also relates to the extent of cloudiness: increased cloudiness increases the Earth's albedo, decreasing the solar radiation reaching the Earth's surface and thus lowering the surface temperature (negative feedback effect), and vice versa [16]. Increased temperature resulting from an increased concentration of the 'permanent' greenhouse gases increase evaporation rates, and hence the extent of the greenhouse effect attributable to water vapour since evaporation (including transpiration from plant canopies) increases to a greater extent than rainfall.

Significant constraints on models of the effects of increased 'permanent' greenhouse gases on climate can be achieved by considering past climate change and atmospheric composition. Modelling the climate at the Last Glacial Maximum some 18,000 years ago shows that Milankovic cycle parameters can not reproduce southern hemisphere glaciations when the carbon dioxide is set at post-glacial concentrations (about 280 molecules carbon dioxide per million molecules of total permanent gas in the atmosphere), but can reproduce them when carbon dioxide is set at the concentrations known to have occurred at the Last Glacial Maximum, i.e. as little as 180 molecules carbon dioxide per million molecules of permanent gas [16]. However, we are now, at some 375 molecules carbon dioxide per million molecules of permanent gas, outside the range of carbon dioxide concentrations found over at least the last 420,000 years, so comparisons with the past to constrain the models of the future environment must go back well beyond 420,000 years[16].

As to biotic effects of the increases in carbon dioxide and in temperature, it is often difficult to tease out the influence of carbon dioxide and temperature from other direct and indirect anthropogenic effects. Before anthropogenic influences on carbon dioxide and temperature there were extinctions of large terrestrial vertebrates over a period of tens of thousands of years toward, and just after, the end of the last glacial episode, some of which may be attributable to human influences [12-14]. Certainly these large animals had survived earlier late-glacial periods. There are certainly very significant extinctions occurring today, for example in Britain [15], which have led to suggestions that we are in the sixth global mass extinction.

It is not clear how much of these extinctions can be attributed directly to anthropogenic environmental change. There are certainly grounds for believing that there are increased disease risks for aquatic and terrestrial organisms as a result of global change [19]. An interaction between global and local changes in the atmosphere involves the photochemical generation of tropospheric ozone using nitrogen oxide radicals, 70% of which are anthropogenic and occur in industrialised areas, and volatile hydrocarbons [20,21]. The production of isoprene, a major tropospheric hydrocarbon, by some plants is inhibited by increased carbon dioxide, so that air quality in terms of a lower ozone concentration may be increased with increasing carbon dioxide [22]. However, it has been shown the build-up of soil organic carbon under increased carbon dioxide, which acts as a negative feedback on the increasing atmospheric carbon dioxide, is inhibited by ozone [23]. Regardless of the effects of ozone on the removal of CO_2 from the atmosphere into long-term (years-decades-centuries) storage, it is clear that tropospheric ozone could also have significant effects on the relative fitness of species of plants and animals.

Conclusions. Current evidence suggests that there has been a significant increase in mean global temperature over the last century, and that the increased greenhouse gas concentration is causally related to this increase. This temperature increase will almost certainly continue over the century and more, and will interact with other components of environmental change and aspects of human activities in altering the potential for ecosystem services for the support of man and other biota and in leading to extinctions. Clearly biota have withstood extreme events in the previous great extinctions, and the extinction of many species of micro-organisms would be very unlikely even as a result of very extreme events [3]. However, this continuity of life, and even of many higher taxa of large organisms, through mass extinctions, should not cause us to think that global environmental change is not a problem. Life survived earlier extreme events, but did not have man's impact to contend with. From an anthropocentric viewpoint environmental change is a significant threat to at least our current way of behaving, and the survival of life through earlier major traumatic events does not mean that our civilisation can survive.

References

[1]Hallam, A. (1989). *Great Geological Controversies (2nd edition).* Oxford University Press, Oxford.

[2]Hancock, P.L. & Skinner, B.J.E. (2000). *The Oxford Companion to The Earth.* Oxford University Press, Oxford.

[3]Cockell, C.S. (2003). *Impossible Extinction. Natural Catastrophes and the Supremacy of the Microbial World.* Cambridge University Press, London.

[4]Knoll, A.H. (2003). *Life on a Young Planet. The First Three Billion Years of Evolution on Earth.* Princeton University Press, Princeton, NJ.

[5]Bekker, A., Holland, H.D., Wang, P-L., Rumble, D.I., Stein, H.J., Hannah, J.L., Coetzee, L.L. & Beukes, N.J. (2004). *Nature* **427**, 120.

[6]Wilman, R.A.,Jr., Hickey, L.J., Dickinson, M.B., Berman, R.A., Robinson, J.M., Dietrich, M., Essenhigh, R.H. & Wildman, C.B. (2004). *Geology* **32**, 457-360.

[7]Pierrehumbert, R.T. (2004). *Nature* **432**, 677.

[8]Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G.

Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E. & Stivenard, M. (1999). *Nature* **399**, 429-436.

[9]EPICA community members. (2004). *Nature* **429**, 623-628.

[10]Cuffey, K.M. & Vimeux, F. (2001). *Nature* **412**, 523-527.

[11]Sigman, D.M. & Boyle, E.A. (2000). *Nature* **407**, 859-869.

[12]Roberts, R.G. Flannery, T.F., Ayliffe, L.K., Yoshida, H., Olley, J.M., Prideaux, G.J., Laslett, G.M., Baynes, A., Smith, M.A., Jones, R., & Smith, B.L. (2001). *Science* **292**, 1888-1892.

[13]Barnosky. A.D., Koch, P.L., Feranec, R.S., Wing, S.L. & Shabel, A.B. (2004). *Science* **306**, 70-74.

[14]Shapiro, B., Drummond, A.J., Rambant, A., Wilsom, M.C., Matheus, P.E., Sher, A.V., Pybus, O.G., Gilbert, M.T.P., Barnes, I., Binladen, J., Willerslev, E., Hansen, A.J., Baryshnikov, G.F., Burns, J.A., Davydov, S., Driver, J.C., Froese, D.G., Harington, C.R., Keddie, G., Kostintsev, P., Kunz, M.L., Martin, L.D., Stephenson, R.O., Storer, J., Tedford, R., Zimov, S. & Cooper, A. (2004). *Science* **306**, 1561-1565.

[15]Thomas, J.A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D., Asher, J., Fox, R., Clarke, R.T. & Lawton, J.H. (2004). *Science* **303**, 1879-1881.

[16]Kump, L.R. (2002). *Nature* **419**, 188-190.

[17]Levitus, S., Antonov, J.I., Wang, J., Delworth, T.L., Dixon, K.W. & Brocolli, A.J. (2001). *Science* **292**, 267-270.

[18]Oresces, N. (2004). *Science* **306**, 1686.

[19]Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., Ostfeld, R.S. & Samuelo, M.D. (2002). *Science* **296**, 2158-2162.

[20]Fowler, D., Flechard, C., Skiba, U., Coyle, M. & Cape, J.N. (1998). *New Phytologist* **139**, 11-23.

[21]Stedman, D.H. (2004). *Environmental Chemistry* **1**, 65-66.

[22]Rosensteil, T.N., Potosnak, M.J., Griffin, K.L., Fall, R. & Monson, R.K. (2003). *Nature* **421**, 256-259.

[23]Loya, W.M., Pregitzer, K.S., Karberg, N.J., King, J.S. & Giardinia, C.P. (2003). *Nature* **425**, 705-707.

The SCRI LEAF[1] Innovation Centre:
Agro-ecosystem research which develops and promotes sustainable agriculture strategies and policies for Scotland, UK and Europe

A.N.E. Birch, B. Boag, A.C. Newton, S.C. Gordon, B. Fenton, G. Malloch, P.D. Hallett, P.P.M. Iannetta, S.E. Stephens, S. Neilson, G.M. Wright, B. Marshall, B.M. McKenzie, G.R. Squire, P. Gill & R.Wheatley

Linking Environment and Farming (LEAF) was established in 1991 to bridge the gap between farmers and consumers. For the first time in the UK groups of farmers, environmentalists, food and agricultural organisations, consumers, government and academics from institutes, agricultural colleges and universities have got together to coordinate and promote a unified environmental management system for the farming industry. LEAF was established to develop and promote Integrated Farm Management (IFM), motivated by a common concern for the future of farming and to develop a system of farming that is realistic and achievable for the majority of the UK's farmers. IFM combines the best of traditional farming methods with modern technology, allowing farmers to manage their farms in an informed, professional and caring way. LEAF's whole farm IFM policy, backed by current agro-environmental research, provides the basis for efficient and profitable production which is economically viable and environmentally responsible. IFM integrates beneficial natural processes (e.g. enhanced soil nutrient cycling and biocontrol of pests and diseases using natural enemies) into modern farming practices.

Figure 1 LEAF demonstration farm event.

LEAF's aims are to minimise environmental risks while conserving, enhancing and re-creating that which is of environmental importance, using advanced technologies. LEAF is the leading organisation in the UK promoting and developing IFM, encouraging the uptake of IFM by farmers through practical guidelines, on-farm demonstrations (Fig. 1) and the LEAF Farm Audit for best practice. There are now 45 different lines of food produce that display the LEAF Marque Logo in UK stores. These products are being featured at major UK events including Wimbledon Tennis Championships (Fig. 2), the Royal Show and the Royal Highland Show. The Royal Show exhibit featured Integrated Pest Management tools for raspberry pests, developed by SCRI. The LEAF network now includes 45 Demonstration Farms (LEAF's farmer membership covers 15% of the UK land area and is increasing) and 19 Innovation Centres across the UK (Fig. 3). LEAF is supported by SEERAD, Defra and other governmental bodies, the RSPB, Scottish Natural Heritage, the National Trust and by European-wide initiatives, via the European Initiative for Sustainable Development in Agriculture (EISA; http://www.sustainable-agriculture.org/). Ingrid Clayden, representing SEERAD, recently said "I am very happy to be here representing SEERAD and I hope that my presence demonstrates our appreciation for the work done by LEAF in Scotland. I also hope that what I am about to say is seen as an endorsement of the LEAF objectives and the ways in which LEAF seeks to improve farming." The UK Secretary of State for the Environment also supports LEAF, saying "I am very pleased to see this leading example of good practice. It is providing a vital inspiration for farmers who are looking for a profitable and environmentally-friendly

Figure 2 LEAF Marque strawberries at Wimbledon 2004.

[1]Linking Environment and Farming (LEAF) (website www.leafuk.org).

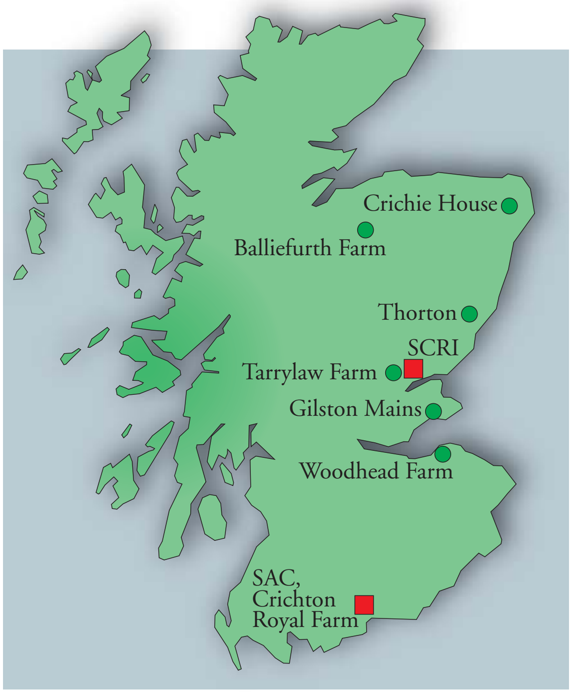


Figure 3 LEAF Scotland map showing Demonstration Farms (●) and Innovation Centres (■).

future. I commend the foresight of LEAF and its members in promoting a realistic and sustainable future for farming."

SCRI joined LEAF as an institutional member in 2002 and was invited to be the first SABRI LEAF Innovation Centre in Scotland in 2003. Our role, with the other Innovation Centres, is to promote current agro-ecological research and to pioneer new approaches that steer and support policy on sustainable land management and integrated farming. The Innovation Centre and related education and public communication of science projects (see below) are open to a wide range of visitors and 'end-users' of our research, including farmers, the general public, schools, environmental groups, the agro-industry sector, supermarket supply chains, governmental policy makers and politicians.

SCRI's on-site environmental research SCRI together with BioSS have extensive expertise on experimental design, data collection (ranging from molecular, gene, cellular, organism, through to ecosystems, landscapes, regions and countrywide), statistical analysis and numerical modelling. Besides developing fundamental and strategic research, we have the capability to demonstrate IFM principles and to develop IFM tools (e.g. pest- and disease-resistant crops; pest trapping technologies; eco-friendly, plant-derived alternatives to synthetic pesticides; molecular ecology and epidemiology of virus vector aphids (Fig. 4)). SCRI also develops research as policy aids for SEERAD, Defra, the EU and developing countries, on important issues like risk:benefit analysis and biosafety of genetically modified crops. Funding for agro-environmental research at SCRI comes from a wide range of sources including SEERAD, Horticultural Development Council (HDC), Defra Hortlink, the EU, the International Organisation for Biological Control and the Swiss Agency for Development and Cooperation.

Figure 4 *Myzus persicae,* a key pest and virus vector on several UK crops. This pest is being intensively studied using molecular ecology and population genetics approaches involving SCRI, SASA, SAC and Rothamsted International (described in following article by Fenton *et al).*

Learning from natural ecosystems: Use of barley variety mixtures to stabilise yield and suppress diseases. One of the factors which aggravate sustainability problems in agriculture is the use of monocultures, where every plant in a crop is genetically identical. The environment in which each of these plants grows is heterogeneous, but the plasticity of the plant's phe-

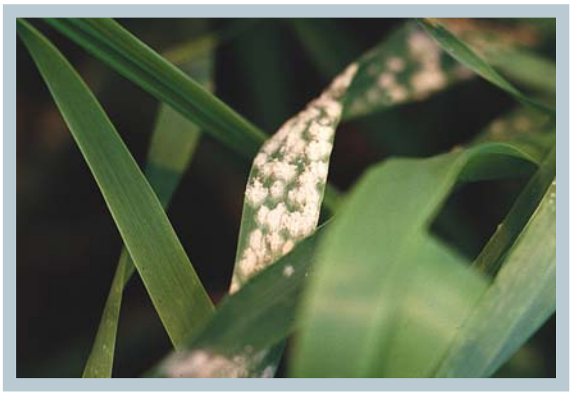


Figure 5 Barley with powdery mildew disease, which reduces yield and increases fungicide usage.

notype to respond to this is limited by the genes expressed in this single genome. Compare this to natural ecosystems, or even to field margins, headlands and hedgerows, where there are not only mixed species, but also genotypes within the species. Observe where disease epidemics occur – in the crop where there is no barrier to the spread of an adapted pathogen and where there is a concentration of plants which are susceptible. Consider also that the highest yielding variety in one year in a particular field is often not the highest yielding in all fields or even in the same field in different years. In other words, growing monocultures leads to vulnerability to stress, be it from pathogens (biotic), or the weather (abiotic), and to instability (Fig. 5).

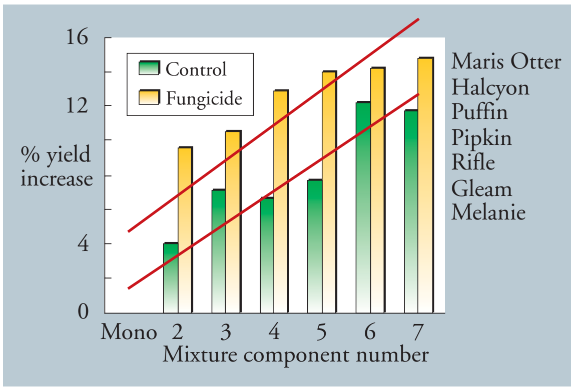


Figure 6 Yield advantage of mixtures compared with the monoculture mean showing increasing benefit with higher component variety number in the mixture.

The solution to these problems is simple - exploit heterogeneity by mixing varieties, or even species where end-user constraints allow. In this way we increase the plasticity of the crop to respond to stress by providing a wider genetic base from which to express the genes which result in the phenotype. Therefore there is much more likely to be a plant which can respond well in every part of the field. There are also likely to be plants which respond well at any given time. The result is a better and more stable yield and higher quality crop, through better utilisation of resources (Fig. 6). Better utilisation of resources applies to nutrients, water and light interception. To access the nutrients and water roots are required in all the appropriate parts of the soil at the right time. Again, heterogeneity, plants with varied rooting characteristics, will give the crop advantages.

In our work to reduce inputs, especially pesticides and nutrients which have a negative impact on the environment, increasing the plasticity or buffering capacity of crops by increasing heterogeneity is an essential component. The issues this raises, particularly quality issues perceived by end-users, are being addressed and often found to be either groundless or can be easily remedied. Indeed, some of the anticipated problems have turned out to be benefits such as unexpected enhancement of alcohol yield from barley mixtures used in distilling (Fig. 7). They may also have advantages in new crop uses such as for bioethanol fuel production where yield component utilisation options are different from, say, barley for whisky distilling.

In farm practice audits, crop agronomy considerations should include not just variety choice, fertilisers, time of planting, pesticides etc, but also use of crop heterogeneity, variety mixtures or blends to enhance the flexibility, plasticity, buffering capacity, or resilience of the crop. It is not the answer for all crops, but it can certainly be considered for far more than are currently being entertained.

Minimising environmental stresses: The soil disturbance experiments This experiment began in 2003 to examine how disturbing soil with tillage influences plant productivity, soil sustainability, and agricultural ecosystems. Physical disturbance was manipulated using cultivation common in Scottish agricultural production, newer approaches aimed at minimising soil damage and nitrate losses to ground water, and potentially harmful practices chosen to manipulate the soil biophysical environment. Our aim is to produce different soil environments to underpin fundamental research on ecosystem dynamics and plant sciences, and support applied research on soil tillage.

The design of the field experiment using five tillage treatments combined with different nitrogen inputs to

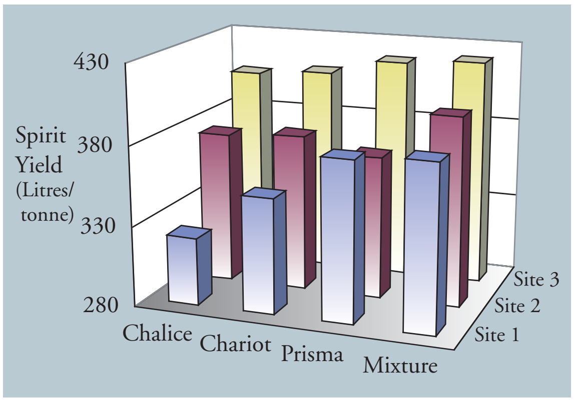


Figure 7 Spirit yield from barley monocultures and mixtures showing highest yield and yield stability across sites from the mixtures. Trials grown by SAC.

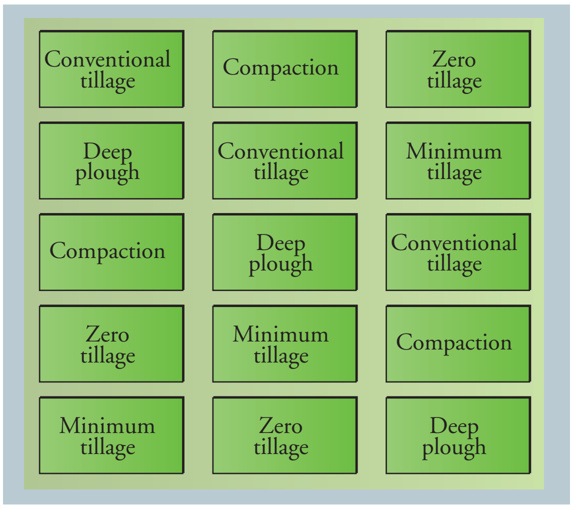


Figure 8 Soil disturbance. Experimental treatments are (1) Conventional ploughing to 20cm (mouldboard); (2) Zero Tillage (direct drilling); (3) Minimum Tillage (disk only); (4) Heavy Disturbance (ploughing to 40cm and disking) and (5) Heavy Compaction (heavy tractor wheeling). The buffer between plots provides a 'bank' for insects and soil organisms.

study disturbance effects on winter barley ecosystem over several years is shown in Fig. 8.

Overlaying the soil disturbance experiment, we are studying how four winter barley cultivars, planted in monocultures and all combination of mixtures, interact with the different soil conditions. Mixtures may, on average, outperform monocultures as the greater diversity in plant characteristics is better at exploiting the soil and aerial environment and withstanding stresses like pathogens and poor weather. There are already some obvious visible differences that can be seen in the field experiment (Fig. 9). The difference in plant height across the different beds of barley is due to different fertiliser rates, the shorter plants having half the normal level. Crop residues can be seen on the surface of the Zero Tillage sites, where plant pathogens are also higher.

This experiment incorporates a wide range of disciplines and state-of-the-art approaches in ways not done previously. We are collecting data about the plants, soil and environment. SCRI ecologists are examining the impact of soil disturbance above and below ground, on the crop, associated weeds, soil micro- and macro-organisms and invertebrate populations. Chemists are monitoring the forms and cycling of plant nutrients and carbon. Soil scientists are determining the structure of the soil, the water available to plants, and the resilience of the soil to environ-

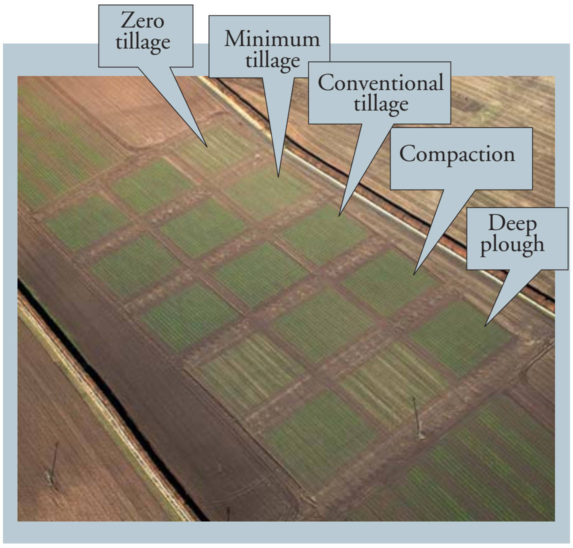


Figure 9 Soil disturbance trial showing the arrangement of 30 x 34 m treatment areas in one of the replicates.

mental stresses. This work underpins that of the plant scientists investigating the physiological response of plants, the spread of pathogens, root proliferation, and the performance of barley mixtures under different levels of soil disturbance. Future work will extend to controlled laboratory studies and smaller field experiments on different soils. We expect this work will help unravel the complexity of agricultural ecosystems, and feed into SCRI's plant breeding and genomics programmes by generating understanding of plant-soil interactions, and lead to environmentally sustainable land management.

Research on LEAF Demonstration Farms One such programme monitors and manages raspberry beetle (Fig. 10) without pesticides by understanding ecological connections between wild host plant reservoirs,

Figure 10 Raspberry beetle adults are attracted to both the reflected colour and scent of raspberry flowers.

open field crops and protected crops. This long-term, chemical ecology research was initiated in 1992 when Swiss collaborators in Wadenswil provided SCRI scientists with white sticky traps, using visual attraction, as a means of monitoring raspberry beetles (white traps reflecting wavelengths similar to raspberry flowers Fig. 11). Between 1994 and 1996 SCRI entomologists and phytochemists developed sensitive electrophysiological and behavioural bioassays to identify the key volatile chemicals emitted from raspberry flowers which attract raspberry beetle to its host for

Figure 11 White sticky trap for monitoring raspberry beetles emerging from wild host plant reservoirs (wild raspberries, brambles, hawthorn) before raspberry crops flower.

feeding, mating and egg laying (Fig.12). The combination of colour and smell, mimicking a giant host flower, has enhanced trapping rates by up to fifty times compared with the original white sticky trap. Enhanced traps have been tested in several European and Scandinavian countries under an EU funded CRAFT project (1998-2000) entitled RACER. The white sticky trap is now so effective that it becomes saturated by raspberry beetles after 2-3 days. SCRI scientists and an HDC-funded PhD student are currently testing an improved trap with a slow release attractant that lasts all season, in collaboration with a specialist UK company. Pilot studies on a local LEAF farmer's plantation in Fife during 2004 have already demonstrated that raspberry beetles can be effectively monitored and trapped emerging from wild hosts (wild *Rubus* species, hawthorn Fig. 13). It is hoped that the new, improved beetle trap at optimal positioning in field and tunnel-grown raspberries will manage this important pest below economic levels, without having to use current levels of conventional pesticides. A new research proposal (Defra Hortlink), involving SCRI and other institutes together with raspberry growers, supermarket chains, ADAS and an IPM company, is being now approved for submission so that UK end-users can benefit from SCRI's IPM tools and systems for a range of crops.

Environmental management of the SCRI research farm The establishment of SCRI as a LEAF Innovation Centre to demonstrate new areas of research in sustainable agriculture has increased the ground area dedicated to 'green' activities (Fig. 14). 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 wind-breaks, species-rich grassland (Fig. 15), beetle banks and mixed native hedgerows (Fig. 16) (hawthorn, blackthorn, elder,

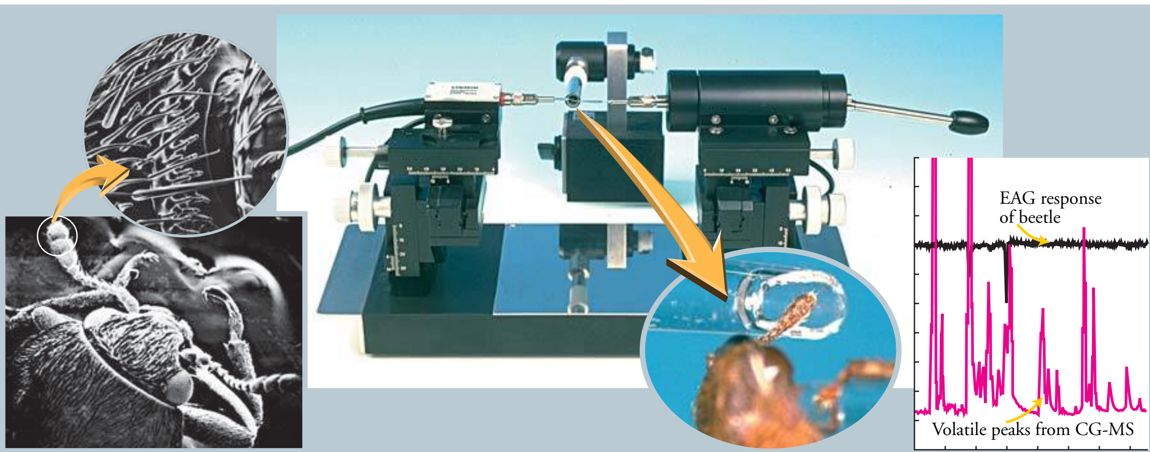


Figure 12 An electro-antennogram (EAG) coupled to a gas chromatogram-mass spectrometer (GC-MS) was used to identify the key raspberry beetle attractants from the hundreds of volatile chemicals in the flower odour.

Figure 13 SCRI's improved raspberry beetle trap with a lure of slow release floral attractant which lasts all season in open field raspberry plantations or within plastic tunnels.The trap is being developed and tested with several commercial partners.

Figure 15 Wild flower strips have been sown as special field margins to promote beneficial insects including pollinators, predators and parasitoids as well as other soil organisms, which all help by providing "ecological services" to crop plants.

hazel, alder, holly and dog rose). The 10-hectare broad-leaf woodland (oak, ash, birch, wild cherry, 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 SCRI farm is not a LEAF Demonstration Farm nor is it a commercial farm in that we often have to encourage adverse environments such as in pest and disease nurseries and reservoir areas to assess plant response to these biotic stress factors and select for genetic resistance in our plant breeding material.

The presentation of experiments has been improved by the grassing of field roadways, reducing the need for herbicide sprays and enhancing the biodiversity within the grass sward around experimental plots. 'The Living Field Community Garden' (see Environmental Education) is being set up to show the links between science, agriculture and the environment by the use of demonstration plots, interactive exhibits and information boards. The site includes a small pond, with adjacent bog area, and a wild flower meadow with hedges and trees to provide shelter for a variety of birds and insects. This initiative complements the Institute's other environmental and sustainable agriculture activities.

Wildlife Audit The Scottish Crop Research Institute has been intensively farmed as a horticultural and arable farm for 50 years, with no livestock during that period. This has meant that there are very few refugia for wildlife. Although there are some hedges, these are mainly beech and until recently there have been very few native berry bearing shrubs and trees on the farm that might be used by birds e.g. hawthorn. An initial wildlife audit was undertaken during the April 2003

Figure 14 Aerial view of the experimental farm at SCRI.

Figure 16 Mixed species hedgerow provides food and nesting places for birds.

Figure 17 Peacock butterfly on *Buddleia*, an example of biodiversity promoted on SCRI's farm by using environmentally-sensitive farm management methods

and a range of animals and bird species were recorded but generally in low numbers. Blackbird, oystercatcher, woodpigeon, grey partridge, shelduck, curlew, pheasant, chaffinch, house sparrow, songthrush, pied wagtail, mallard and skylark were observed. Of these, shelduck, blackbird and oystercatcher were known to nest, the latter two species around the farm buildings. There were occasional signs of squirrels (probably red) and foxes on two of the fields, while roe deer were observed in one field. Rabbits, in relatively low numbers, were found virtually throughout the farm but in a few fields they were present in sufficient numbers to probably cause damage to crops, at least at the field margins. Nests and runs used by both field mice and voles were also seen. It is interesting to note that, although they are known to be present, no hedgehogs were seen during the survey and there was no evidence of moles on the farm which probably reflects low earthworm populations. There was also no evidence of badgers or of bats using any of the buildings.

The sowing of grass strips around the margins of some fields for wildlife (Fig. 15) should encourage a number of ground nesting birds e.g. partridge but the results of the survey in April/May 2004 did not significantly differ from that of 2003, except that yellowhammers were relatively common in 2004. Although significant benefits for wildlife resulting from changes in farming practices and management will take time, it is expected that they should become manifest in the next few years (Fig. 17).

Environmental education LEAF gives SCRI access to a group of farmers interested in reduction of agrochemicals and promoting environmentally friendly farming practices. This aids the two way flow of ideas which enriches research and solves problems for farmers. It also enables SCRI research to be carried out on LEAF members' farms.

Promotion of SCRI is enhanced by the LEAF Innovation Centre status. In March we promoted a joint LEAF/St Andrews University meeting "What is Environmentally Friendly Food Production?" The SCRI research on the impact of tillage and compaction on soils was presented by Dr Geoff Squire and aroused much interest amongst the farmers present. Rights of way through the Institute farm have been made into a "Science Stroll" and notice boards were made by joinery students at Dundee College and SCRI staff (Fig.18). There are two at present, with plans for more at strategic points on the walk giving information on what walkers might expect to see. There is information about SCRI and the environmental research conducted here and, by the wild flower meadow, an illustration of a food web and pictures to aid the identification of wild flowers and insects.

We have collaborated at events like the Royal Show and the Royal Highland Show by distributing information about LEAF and by LEAF promoting our environmental research. The LEAF exhibit at the Royal Show incorporated a poster showing the raspberry beetle traps referred to earlier.

The public welcome opportunities to access information on crop science and its' relevance to their everyday lives. Visits to SCRI by schools, college, university and other groups are extremely popular and have been increasing over the past year (Fig. 19).There is a high level of interest in how agriculture, science and the environment are related.

Figure 18 SCRI LEAF Innovation Centre Information board as part of the 'Science Stroll' for public awareness of our environmental research.

Figure 19 Dundee University Students visiting SCRI.

To assist public understanding of the complexities of these interrelationships, SCRI established an educational garden in early 2004, called the Living Field Community Garden. (Fig. 20). The garden consists of several different habitat demonstration areas, an experimental plot area, composting boxes, a wormery and demonstration boxes showing different soils and root systems. Information boards explain the garden and its contents. The garden is aimed at people of all ages and is located alongside the SCRI Science Stroll. Funding to help establish the garden was obtained from the BBSRC.

Figure 20 Living Field Community Garden.

SCRI are also producing an educational CD and web pages for schools called the Living Field (Fig. 21) that has been funded by the Scottish Executive Education Department (SEED) with support from Learning and Teaching Scotland. This educational resource covers agriculture, environment, science and nature, following the Scottish 5-14 National Guidelines for environmental science. The first three parts are aimed at primary schools and the fourth part is aimed at first and second year secondary school.

Figure 21 The Living Field educational resource.

SCRI was invited to exhibit at the Great Yorkshire Show on 13th – 15th July 2004 as part of the universities exhibit. This prestigious event is held annually in Harrogate and this year the attendance was just over 124,000 people (Fig. 22). Bruce Marshall, Joyce McCluskey and Gladys Wright from Ecosystem Management & Biology Dept presented research on 'The Importance of Seedbank Biodiversity' with a 'hands-on' educational display targeted at the general public. Three different activities were set up using computers, microscopes and seeds. The computer activities included the Arable Seed Identification System (ASIS), which can be found at www.scri.sari.ac.uk/asis, 'The Living Field' and an activity to exhibit the diversity of arable seedbanks, examining seeds including size, colour, shape and unusual textures using microscopes and finally sowing seeds for taking home.

Figure 22 Members of the public were enthusiastic about SCRI's display at the Great Yorkshire Show. Comments and feedback from the public are generally very positive and the SCRI staff involved found the exhibition over the three days to be very rewarding and worthwhile.

Mechanisms & Processes

J.W.S. Brown, K.J. Oparka, L. Torrance, S.A. MacFarlane, P.R.J. Birch & A.G. Roberts

All three programmes: Gene Expression (GE), Cell-to-cell Communication (CCC) and Plant Pathogen Interactions (PPI) have seen significant achievements in the last year. A series of "firsts" in plant and pathogen biology demonstrate the excellence of science and technology development carried out within the theme. In particular, the high quality molecular and cell biological expertise has been applied to understanding the subtlety and complexity of gene expression in plants and their pests and pathogens, and the interactions between these organisms.

The phenotype of a plant, whether at the macro-level of plant architecture or organ development or at the micro-level of the plant cell, is governed by regulated changes in gene expression. How plant growth and metabolism is altered under different conditions and how a plant responds to infection or attack by pests and pathogens again is determined by complex patterns of gene expression. Gene expression is regulated mainly at the transcriptional and post-transcriptional levels. The availability of fully determined genome sequences from some plants and pathogens, and the ever-increasing genomics and sequence information of other species, underpins much of plant and crop science and is widely used in the research of the theme.

The last 4 – 5 years has seen a remarkable increase in the importance of post-transcriptional gene regulation with the discovery of silencing and small interfering RNAs, microRNAs involved in many aspects of developmental control, RNA processing and alternative splicing events in development and plant responses, and the dynamic role of the nucleus and nuclear bodies in many of these processes. Research at SCRI is contributing to the international effort in these areas, but more importantly, the unique mix of expertise at SCRI allows us to integrate knowledge and skills and provide new scientific insights for exploitation.

Post-transcriptional control of gene expression in higher eukaryotes involves areas of RNA processing such as alternative splicing and messenger RNA (mRNA) turnover. Alternative splicing of precursor messenger RNAs (pre-mRNAs) in humans is an extremely important source of functional diversity where around 70% of genes are alternatively spliced and over 150,000 – 200,000 proteins can be generated from 30,000 – 40,000 human genes. Although alternative splicing is less prevalent in plants, we estimate that a significant proportion of plant genes (up to 20 – 25% or around 6,000 – 7,000 genes) are alternatively spliced.

Alternative splicing is regulated by short sequences in pre-mRNA transcripts (called splicing enhancer and silencer sequences), and by the levels of *trans*-acting proteins which interact with such sequences. Levels of these proteins are different in different cells and are affected by external stimuli such as light, temperature and other biotic and abiotic stresses. Through the study of genes undergoing alternative splicing and the consequences in terms of protein function, we will provide novel insights into plant responses to environmental conditions and stresses. This year, Craig Simpson (GE) has identified one of the first plant exon splicing enhancer sequences and a splicing regulator protein (PTB) has been cloned to address control of alternative splicing in plants (see following article by Simpson, C.G. *et al*).

Compartmentalisation of components of gene expression in different nuclear structures is of increasing importance in gene regulation, and dynamic movement of components is known to occur in response to changes in cell metabolism or in response to environmental conditions. Recently, a number of plant nuclear bodies or structures have been shown to be involved in RNA processing and in signalling responses to, for example, light and growth hormones demonstrating another level of complexity in expression regulation and plant response. The most prominent nuclear body, the nucleolus, has many different functions in the metabolism and biogenesis of various RNAs and in processes such as the cell cycle, aging and sensing of cellular stress. One way of addressing the functions of such nuclear bodies is to analyse their protein complement (proteome). In association with colleagues at the John Innes Centre, the University of Dundee and the University of Southern Denmark, we have identified over 200 plant nucleolar proteins as well as potentially novel functions for the plant nucleolus in mRNA export from the nucleus and mRNA decay (see following article by Brown, J.W.S. *et al*). The unique opportunity to compare the proteomes of the nucleolus of plants and humans highlights differences which are of value to understanding the function of the nucleolus in both systems. Finally, the plant nucleolar proteome provides the basis for studying the involvement of the nucleolus in response to stresses at the molecular and cellular levels.

A major challenge of the theme is to understand the interactions of plants and pathogens and how they affect each other's gene expression and viability. One of the most interesting developments is the bringing together of studies on the biology of plant viruses and plant RNA metabolism processes. In particular, plant viruses have been extremely important in the study and dissection of one of the most important phenomena in biology, namely RNA silencing. Silencing or the targeted destruction of foreign RNAs is one form of plant defence and when plant viruses infect cells the plant produces siRNAs which promote destruction of the viral RNA. However, viruses have evolved proteins (called silencing suppressors) as a counter-defence against silencing. Three areas of work in the GE programme provide insights into the function of such proteins and how they interact particularly with normal RNA metabolism processes and organisation within the plant cell. In the first case, Stuart MacFarlane and Tomas Canto (GE) demonstrated that the P19 protein of *Tomato bushy stunt virus* (TBSV) interacts with and causes the relocalisation of a protein called ALY/Ref which is involved in the export of RNAs from the nucleus to the cytoplasm. In the second case, Misha Taliansky and Sang Hyon Kim (GE) showed that the ORF3 protein of *Groundnut rosette virus* was localised to the nucleolus and that this localisation or trafficking through the nucleolus is essential for virus infection throughout the plant. In the third case, Peter Palukaitis (GE) and colleagues in Israel have shown that the *Cucumber mosaic virus* (CMV) 2b silencing suppressor has two, independent nuclear localisation signals, and uses the keryopherin α protein nuclear transport system. These intriguing observations demonstrate how plant viruses have evolved proteins which may either interfere with or hijack normal cellular functions to favour conditions for viral replication.

The importance of gene regulation at the post-transcriptional level has been demonstrated clearly in the regulation of genes involved in the control of flowering time in research carried out by Gordon Simpson (GE). His research will continue to investigate the genetic pathways of flowering control in both the model plant, *Arabidopsis*, and in barley.

Plants display a range of cellular and molecular responses to infection and disease. In animals, one response is programmed cell death or apoptosis where damaged or infected cells are destroyed. Key components in apoptosis in animals are a family of caspase proteases which digest other cellular proteins. Despite plants having an analogous apoptotic process, the hypersensitive response, no caspases have ever been identified. However, this year, Misha Taliansky (GE) along with colleagues at Moscow State University discovered for the first time, caspase-like proteins in plants (see following article by Kim, S.H. *et al*). In a related study, Paul Birch (PPI) and Christophe Lacomme (CCC) identified other apoptotic orthologues active in the hypersensitive response in potato. These discoveries will contribute greatly to our understanding of plant defence.

An integral part of understanding plant-pathogen interactions is the identification and functional characterisation of pathogen genes expressed during infection. Greatest progress in this area is, of course, possible when the entire genome sequence is available. A milestone for SCRI was the generation of the first *Erwinia* genome sequence by Ian Toth and Paul Birch (PPI) which has resulted in a major increase in information about this intriguing bacterium. Bioinformatics tools, developed by Leighton Pritchard (PPI), help manage the information and aid analysis (see following article by Pritchard, L. *et al.*). The analysis has already revealed the presence of a number of novel proteins and chemicals involved in blackleg disease including phytotoxins, and exported necrosis inducing factors.

An important novel finding in the area of late blight research has been the identification by Paul Birch and Steve Whisson (PPI) of the *Avr3a* avirulence gene from *Phytophthora infestans*. In addition, collaborative research with HRI-Warwick has demonstrated that *Avr3a* lies in a genomic region that is conserved with a locus containing an avirulence gene, $ATR1^{NdWsB}$, in another oomycete, *Hyaloperonospora parasitica* (*Arabidopsis* downy mildew). Although the gene order is conserved at these loci in the two species, the avirulence genes are very different from each other. Such evolutionary relationships reflect events in pathogen evolution and diversity, and host range and specificity. In a similar vein, John Jones (PPI) and colleagues have identified genes encoding a family of GHF 45 cellulases (cell wall degrading enzymes) in nematodes that have been acquired by horizontal gene transfer from fungi. While gene transfer from bacteria to nematodes has been described previously, this is the first instance of horizontal gene transfer from fungi. These findings show that horizontal gene transfer has played a key role in the evolution of plant parasitism by nematodes on more than one occasion.

A key goal in understanding plant growth and development, and plant-pathogen responses is to gain knowledge of the function of different genes. This is addressed through a variety of biochemical, genetic, molecular and cell biological techniques such as analysis of mutants, global gene expression, imaging and biochemical interactions. Examining the patterns of gene expression in both plant and pathogens, in different tissues and cells, and the changes that occur during development or in response to environmental conditions or the infection process is a key to developing new strategies for crop improvement and disease control. Two of the major technologies in this area are microarray analysis and virus-induced gene silencing (VIGS), established at SCRI over the last 2 – 3 years as part of the Outer Core programme by Peter Hedley (GE) and Christophe Lacomme (CCC) respectively. Microarray analysis allows the rapid assessment of expression profiles of many thousands of genes at the same time. Changes in expression are detected by comparing mRNA populations from plants and pathogens at different stages in their life cycle and during the infection process. This system is currently being used successfully in a number of areas of research across the Institute including the control of pigment synthesis in potato, dormancy in raspberry, abiotic stress in barley, host responses to disease including regulatory and signalling networks in disease development, and changes in pathogen gene expression during infection cycles. VIGS technology will play an increasingly important role in analysing gene function in all areas of biology in the Institute. Emphasis has been given to developing efficient VIGS systems for potato and barley, and its application to diploid and tetraploid potato was demonstrated for the first time this year. VIGS is currently being used to analyse starch biosynthesis and proteins involved in disease resistance in potato. In addition to silencing plant genes, VIGS will also be extremely important in understanding the function of genes from plant pathogens, and will be assisted by the success of Steve Whisson and John Jones (PPI) in developing gene silencing protocols in *Phytophthora infestans* and cyst nematodes (see following article by Whisson, S.C. *et al*).

Further important functional characteristics of plant proteins are their transport and localisation to different parts of the cell, and interactions with other proteins. In CCC the localisations of many different proteins have been determined by fusing their genes to genes encoding fluorescent proteins (FPs) and visualisation of the FP fusion proteins in living cells by confocal microscopy. A programme funded by the Gatsby Foundation uses a high-throughput screening system to identify proteins localised to different cellular compartments (e.g. chloroplast, mitochondria, Golgi, nucleus etc.) following expression of cDNA-GFP fusion libraries from viral vectors. This programme aims to deliver localisation information of benefit to plant scientists throughout the world. Kenny Bell and colleagues (CCC) have optimised the viral vector expression system and created several cDNA-GFP fusion libraries, and have already identified valuable novel markers for subcellular components.

The major thrust of the cell biology research is to understand the structure and function of plasmodesmata – channels connecting plant cells through which molecules and macromolecular complexes (including viruses) pass from cell to cell. Plasmodesmata have proven exceedingly difficult to analyse biochemically. A localisation screen, similar to that described above, successfully identified around a dozen potential plasmodesmatal candidate proteins which are currently being analysed.

The acquisition of a new, state-of-the-art, confocal microscope has greatly increased the ability to exploit novel fluorescent proteins, while advanced techniques such as photoactivation, photoconversion, FlAsH, FRAP and FRET have facilitated studies of protein dynamics. Petra Boevink (CCC) has used the photoactivation of a recently developed GFP derivative for real-time analysis of protein movement between cells (see following article by Boevink, P. *et al.*). Fluorescence resonance energy transfer (FRET), a powerful but difficult technique to examine protein-protein interactions *in vivo*, will be used to extend the research into the Golgi matrix proteins identified by Maita Latijnhouwers (CCC) in a highly successful collaborative project between SCRI and Oxford Brookes University (see following article by Latijnhouwers, M. *et al.*). In addition to the trafficking of various cellular molecules, a major question is how viral components target and modify plasmodesmata to facilitate virus movement. A detailed study of the *Tobacco mosaic virus* movement protein (TMV MP) by Kath Wright and colleagues in CCC used a selection of fluorescent markers for co-expression, photoactivation and fluorescence recovery after photobleaching (FRAP) to extend previous research that indicated that the TMV MP did not use microtubules to target the plasmodesmata, and to develop a new model for TMV movement. This work indicates that the TMV MP uses the endoplasmic reticulum to locate plasmodesmata and depends on the actin/myosin system for movement. Similarly, Tomas Canto and Peter Palukaitis (GE) identified sequences important for the CMV 3a movement protein to localise to plasmodesmata and showed that the 3a protein also did not associate with microtubules as thought previously.

The combination of cell biology and molecular pathology has revealed for the first time the association of the plant endocytic pathway in intercellular movement. Movement proteins encoded by the *Potato mop-top virus* were tagged with fluorescent markers and monitored in living cells, and found to associate with components of the secretory and endocytic pathways. In addition, protein interaction analysis revealed that one of the virus proteins (TGB2) interacted with a tobacco protein belonging to the highly conserved RME-8 family of J-domain chaperones that are essential for endocytic trafficking in *Caenorhabditis elegans* and *Drosophila melanogaster* (see following article by Haupt, S. *et al.*).

Scientists from all three programmes are involved in the application of their research to discovering new ways of controlling plant pests and pathogens. For example, John Jones (PPI) and colleagues from GE are developing novel strategies for control of potato nematodes bringing together expertise in molecular plant pathology and RNA metabolism within the theme. Similarly, Hugh Barker (GE) has been developing novel GM routes for controlling viruses *via* gene silencing. Several approaches have been tested to explore the possibility of designing transformation methods that confer resistance to multiple viruses through a single transgene.

In addition to the successes of research groups in the theme and programmes, there have been notable individual achievements. Karl Oparka, the Programme Leader of CCC received the accolade of being made a Fellow of the Royal Society of Edinburgh and was also appointed to Honorary and Visiting Professorships at the University of Dundee and the Oxford Brookes University respectively. Sanjeev Kumar Sharma, a PhD student in GE won three prizes in the last year to attend an international meeting in San Francisco and for outstanding poster presentations. Finally, Steve Whisson (PPI) was awarded the Peter Massalski prize.

The synergy obtained from combining molecular and cell biology, biochemistry and bioinformatics and the collaborations developed among scientists with wide-ranging expertise and knowledge provide the basis for understanding in detail the gene function of plants and pathogens. The knowledge generated at the molecular and cellular levels is essential to understanding processes of growth and development, and the plant's response to environmental and pathogenic challenges, and more importantly to the development of innovative and original ideas and strategies for exploitation. The quality of science and potential for application is demonstrated by the high impact publications and the success in attracting external income and will be increasingly important for the future.

Sequences that enhance plant splicing.

C.G. Simpson, D. Lewandowska, M.S. Liney, G.P. Clark, C.M. Booth & J.W.S. Brown

Plant gene expression involves the transcription of messenger RNAs (mRNAs) that are translated into proteins which regulate all aspects of plant growth and development. Most plant genes contain introns (nonsense sequences) which are removed from mRNAs by splicing. Splicing depends on the recognition of intron signals by a large RNA and protein complex called the spliceosome. The recognition of signals leading to intron removal is a complex process and is an important level at which gene expression is controlled. A wide range of signals have therefore evolved to allow different genes to be regulated at different times or in different cells. In vertebrates, short intronic and exonic sequence elements either boost (enhancers) or limit (silencers) the use of nearby splice sites. Although splicing enhancers likely function in splice site selection in many plant genes, and contribute to the regulation of alternative splicing, such sequences have not yet been described in plants.

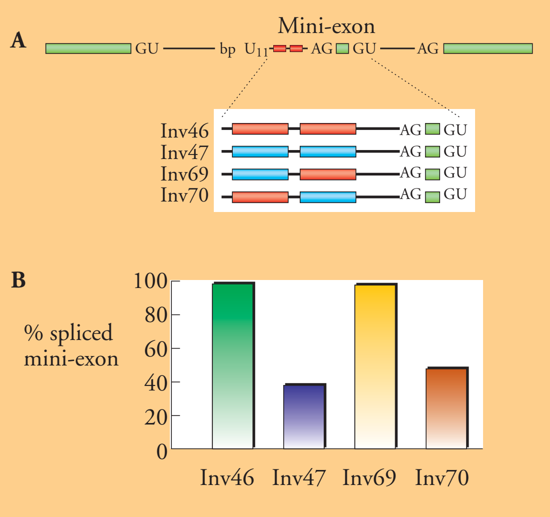


Figure 1 Plant intron splicing enhancer.
A. Two blocks of sequence repeats (red blocks) in the region between the invertase polypyrimidine tract and the invertase mini-exon 3' splice site were mutated (blue blocks) in the construct Inv46, both singly (Inv69 and Inv70) and as a double mutation (Inv47). **B.** Splicing analysis for the four constructs is shown graphically and reveals mutation of the downstream sequence block leads to reduction in splicing of the mini-exon.

Plant Intronic Splicing Enhancer Constitutive splicing of the potato invertase mini-exon 2, which is only 9 nucleotides (nt) long, requires a branchpoint sequence and a polypyrimidine tract located about 50 nt upstream of the mini-exon.[1,2] The sequence between the polyprimidine tract and 3' splice site is 38 nt long and consists of two GATG/pyrimidine repeats. To investigate the importance of these two elements in invertase mini-exon splicing, mutations were made to the pyrimidine region of the two repeats both singly (inv69 and inv70) and as a double mutation (inv47) (Fig. 1A). When the downstream repeat was mutated, mini-exon inclusion was reduced to between 40 and 50% of spliced transcripts (Fig. 1B). This shows that the second of the two repeat sequences is important for enhancing the splicing of the mini-exon and represents a novel intronic splicing enhancer.

Plant Exonic Splicing Enhancer U12-dependent introns are a class of non-abundant introns with non-canonical 5' and 3' splice sites, and branchpoint sequences. In vertebrates, these introns splice less efficiently in comparison to the abundant canonical introns and are thought to regulate the level of expression of the genes in which they are found. In a detailed study of three plant U12 introns we found that splicing in tobacco protoplasts was very poor,

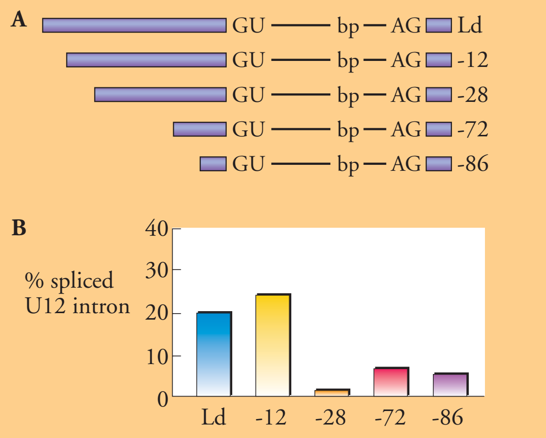


Figure 2 Plant exon splicing enhancer. **A.** Schematic shows progressive deletion of the exon upstream of the U12 intron. Introns are shown as a line bordered by GU and AG, with an internal branchpoint bp. Exons are shown as a coloured box. **B.** Splicing analysis of the 5 constructs is shown graphically and reveals the highest level of U12 intron splicing in the Ld and Ld-12 constructs. Deletion of the region between the -12 and -28 constructs shows a significant reduction in U12 splicing.

with the exception of a U12 intron from the *Arabidopsis thaliana* gene *LUMINIDEPENDENS* (*Ld*), which showed that about 50% of transcripts were accurately spliced. Deletion of the surrounding exons showed the upstream exon to be essential for this efficient splicing of the intron. A series of smaller deletions that removed 12, 28, 72 and 86 nt from the upstream region of the exon showed a large reduction in intron splicing efficiency in tobacco protoplasts from the full length exon and -12 deletion to the remaining deletions (Fig. 2A and B). This shows that the region between the -12 and -28 deletions contains a sequence which enhances *Ld* U12 intron splicing. Computer analysis using vertebrate exon splicing enhancer sequences has identified a potential splicing enhancer in the region between -12 and -28.

This is the first time that intron and exon splicing enhancer elements have been characterised in any detail in plants. Such sequences will be important in understanding gene regulation and it will be of great interest to find how common these splicing signals are in different plant species, how diverse the sequences are and the influence they play on both constitutive and alternative plant pre-mRNA splicing in plant growth and development.

References

[1] Simpson,C.G., Hedley,P.E., McQuade,C.M., Lyon,J.M., Clark,G.P., Machray,G.C. & Brown,J.W.S. (1998) *Scottish Crop Research Institute Annual Report* **1997/98**, 71-73

[2] Simpson,CG., Clark,G. Watters,J. & Brown,J.W.S. (2000) *Scottish Crop Research Institute Annual Report* **1999/2000**, 111-113

Novel functions for the plant nucleolus?

J.W.S. Brown, D. Lewandowska, S.H. Kim, T. Canto & S. Macfarlane

Gene expression is regulated at different levels including transcription; processing and degradation of messenger RNAs (mRNAs); and translation and turnover of proteins. Transcription and processing are functions of the nucleus and it is now clear that the nucleus is a highly structured organelle with functionally distinct compartments or regions. Major domains are chromatin and heterochromatin regions containing chromosomes and the inter-chromatin spaces. The latter contains nucleoplasm and a number of nuclear bodies with a range of functions. In animal cells, the nucleolus, Cajal bodies, splicing speckles, gems and paraspeckles etc. have been identified. Their functions are currently under intense investigation but it is clear that they are an integral part of the dynamics of nuclear processes involved in gene expression.

The most prominent nuclear body is the nucleolus. Classically, the nucleolus is involved in ribosomal RNA (rRNA) transcription and processing, and the assembly of ribosomal subunits, which following export to the cytoplasm form ribosomes for translation of mRNAs into proteins. In addition, the nucleolus is involved in processing and export of other RNAs, assembly of some RNA-protein complexes, the cell cycle and aging. More recently, in human, the nucleolus has been suggested to have an important role as a sensor of cell stress where external and internal factors compromise nucleolar integrity and trigger cell division arrest and even cell death. The multifunctionality of the nucleolus in terms of RNA metabolism and more general cellular functions is intriguing, particularly in terms of how cells respond to changing environmental conditions.

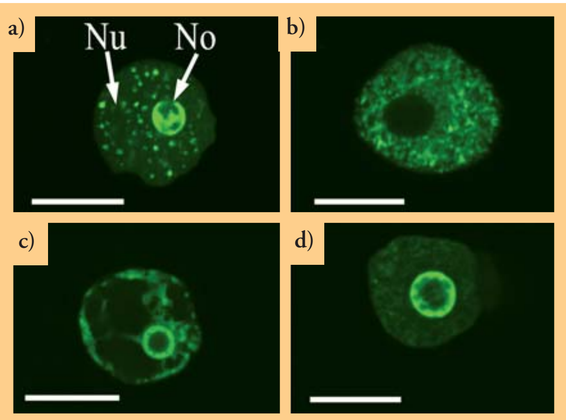


Figure 1 Nuclear and sub-nuclear localisation of the four *Arabidopsis* ALY proteins of the exon junction complex in *Nicotiana benthamiana* cells. **a)** ALY1, **b)** ALY2, **c)** ALY3, **d)** ALY4. Nu – nucleoplasm; No – nucleoli.

To understand the range of different functions in which the nucleolus is involved, the protein composition (proteome) of the plant nucleolus has been examined. This analysis was carried out in the model plant, *Arabidopsis*, due to the availability of the genome sequence providing a peptide database for protein identification[1] in collaboration with Prof. Peter Shaw (John Innes Centre), Prof. Angus Lamond (University of Dundee) and Prof. Matthias Mann (University of Southern Denmark). The 217 identified proteins have been directly compared to a proteomic analysis of human nucleoli. Comparison of the two proteomes showed that almost 70% of the *Arabidopsis* proteins have homologous proteins in the human dataset. Sixty-eight of the plant proteins did not have homologues in the human nucleolar proteome. Of these, 26 (12%) were plant-specific and 39 (18%) had homologues in human, but the proteins were present only in the plant nucleolar proteome but not in that of human suggesting differential localisation.

The value of such comparative proteomic analyses between widely divergent species is demonstrated by the presence of proteins involved in the exon junction complex (EJC) in the plant nucleolar proteome. This protein complex is involved in the export of mRNAs from the nucleus to the cytoplasm, in mRNA decay and in mRNA movement within the cell. The association of these proteins with the nucleolus was unexpected as they are thought to be excluded from the nucleolus in animal cells. The localisation of different EJC components was examined by expressing GFP fusion proteins in both *Arabidopsis* and *Nicotiana benthamiana*, which confirmed their nucleolar association (Fig. 1). These results suggest novel roles for the plant nucleolus in mRNA export or mRNA decay, in addition to its potential function in some virus infections[2]. Current biochemical, molecular and cell biological research is aimed at producing a complete proteomic analysis of the plant nucleolus and elucidating these novel nucleolar functions and their importance to plant gene expression.

References

[1] Brown, J.W.S., Clark, G.P. & Lewandowska, D. (2004) *Scottish Crop Research Institute Annual Report* 2002/2003, 93.

[2] Taliansky, M., Kim, S.H., Ryabov, E.V., Reavy, B. & Robinson, D.J. (2004) *Scottish Crop Research Institute Annual Report* 2002/2003, 94.

Plant caspase, a missing link in plant apoptosis

S.H. Kim, N.V. Chichkova[a], A.B. Vartapetian[a] & M.E. Taliansky

Programmed cell death (PCD), or apoptosis, is a fundamentally important process that maintains the integrity and homeostasis of organisms, regulates their growth, development and responses to pathogen attacks and abiotic stresses. Caspases (cysteinyl aspartate-specific proteinases) have been identified as the main "executioner elements" in cell-suicide machinery, and have been shown to play a critical role in mammalian PCD (Fig. 1). Caspases are responsible for the proteolysis of key proteins that are known to be selectively cleaved at the onset of apoptosis. Caspase-mediated protein fragmentation eventually leads to cell death and caspase knockouts or caspase-specific peptide inhibitors, based on sequences cleaved by caspases, counteract apoptosis in animals. In plants, several tissues or whole organs undergo PCD as part of normal development or in response to environmental stresses. Moreover, the hypersensitive response (HR) is a form of rapid, localised PCD that prevents the spread of pathogens in resistant (incompatible) interactions. Morphological features of apoptosis, such as membrane blebbing, chromatin condensation and DNA fragmentation can be observed in the HR. However, in spite of the striking similarities between PCD pathways in animals and plants, the case for any existence of caspases in plants has been controversial. Although some specific inhibitors of animal caspases have been shown to affect development of PCD in plants, no direct homologues of animal caspase genes have been identified in plants.

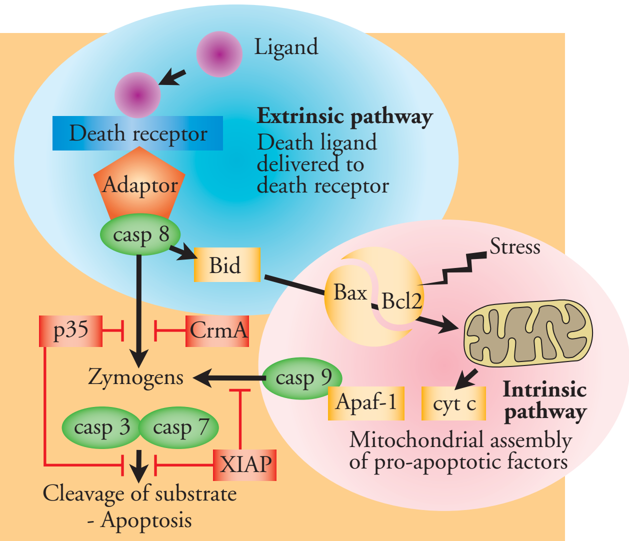


Figure 1 Biochemical events governing apoptotic cell suicide in mammalian PCD. Two initiation pathways (intrinsic and extrinsic), triggered by separate events, converge at a common point to execute apoptosis. Natural inhibitors (red boxes) affect different points on the pathways. The extrinsic pathway is triggered through extracellular ligation of death receptors and their ligands. The intrinsic pathway responds primarily to cellular stress with a mitochondrion acting as an important integrator. Pro- and anti-apoptotic members of Bcl2 family (Bid, Bax, Bcl2) regulate release of cytochrome c (cyt c) leading to activation of caspase 9. Both pathways activate the executioner proteases, caspases 3 and 7 (active forms of caspases shown in green).

Recently in collaboration with Moscow State University (Russia) and Beckman Research Institute (California, USA) we have found this "missing link" in the plant PCD pathway and identified a caspase-like protease, which is activated and counteracts PCD in tobacco plants during *N*-gene mediated HR triggered by *Tobacco mosaic virus* (TMV)[1]. In our work, the nuclear *Agrobacterium tumefaciens* VirD2 protein was used for detection, identification, and purification of a tobacco caspase, based on our prediction that this protein might represent a genuine caspase target. Indeed, we demonstrated that this protein could be specifically cleaved at two sites (TATD and GEQD) by human caspase-3. The VirD2 protein was fused with green fluorescent protein (GFP) and expressed from a TMV-based vector. In these experiments TMV also played the role of inducer of the HR. When the HR was induced, rapid re-localization of the target GFP-VirD2 derivatives from the nucleus to the cytoplasm occurred because the nuclear localisation signal (NLS) became detached from GFP (Fig. 2). Mutational analysis of potential cleavage sites and MALDI mass spectrometry of the cleavage products have identified two sites at which the GFP-VirD2 protein is cleaved by a plant enzyme activated during TMV-mediated HR *in vivo* (TATD and GEQD) that are identical to those identified for the caspase-3 in the experiments *in vitro*[1]. A proteolytic activity capable of specifically cleaving the model substrate at TATD was purified from these leaves. A tetrapeptide aldehyde designed and synthesized on the basis of the elucidated plant caspase cleavage site prevented fragmentation of the substrate protein by plant and

[a] A.N. Belozersky Institute of Physico-Chemical Biology, Moscow State University, Moscow 119992, Russia.

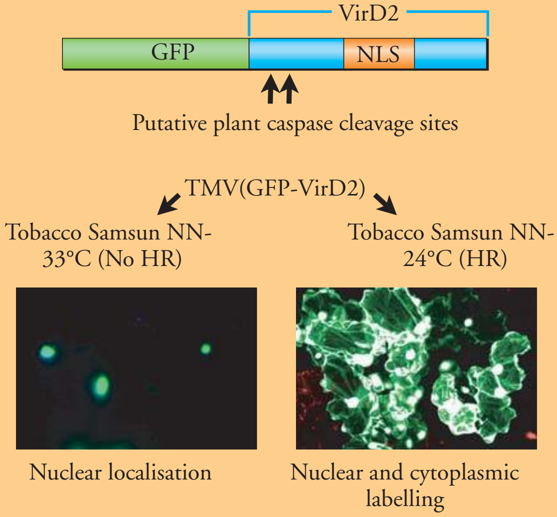


Figure 2 Re-localisation of the target GFP-VirD2 protein from the nucleus to the cytoplasm during the HR as a result of plant caspase activation.

human caspases *in vitro* and counteracted TMV-triggered HR *in vivo* (Fig. 3).

Conclusions and prospects Our data provide a first characterization of caspase-specific protein fragmentation in apoptotic plant cells, with implications for the importance of such an activity for implementation of plant PCD. The plant enzyme identified in our work represents a novel functional analogue of animal caspases that may contribute to plant resistance to pathogens and abiotic stresses. Future work will provide novel "plant caspase" genes that may be directly deployed to develop durable disease resistance in different crops including barley and potato.

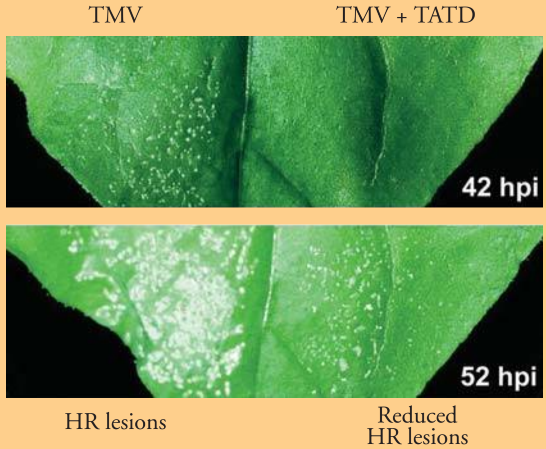


Figure 3 A tetrapeptide aldehyde, biotinyl-TATD-CHO partially inhibits formation of necrotic lesions in tobacco plants infected with TMV (hpi = hours post-inoculation).

Reference

[1] Chichkova , N.V., Kim, S.H., Titova, E.S., Kalkum, M., Morozov, V.S., Rubtsov, Yu.P., Kalinina, N.O., Taliansky, M.E. & Vartapetian, A.B. (2004) *Plant Cell* **16**, 157-171.

Pathways of vegetative development via embryogenesis in *Solanum tuberosum* L.

S. Millam, S.K. Sharma, G. Bryan, V. Matti-Rokka[a] & J. Middlefell-Williams

The concept of totipotency, unique to plants and first proposed by Schwann and Schleiden in 1838, whereby each individual plant cell retains the genetic ability to regenerate back into an intact plant has been exploited for many years. In the laboratory, isolated plant tissues can be induced to de-differentiate and re-differentiate using plant growth regulators and this technology underpins many of the methods used for gene transfer in plant species such as potato. Furthermore, the ultimate demonstration of totipotency whereby an isolated individual plant cell (protoplast) can be induced to divide and regenerate has been used in a number of previous projects involving potato and related germplasm at SCRI.

There exist a number of alternative pathways for vegetative regeneration via an embryogenic route, which have not, until recently, been applied to potato. The underlying principles relate to the natural processes of plant cell development and differentiation. This can be demonstrated by the process in seed plants, where sexual reproduction is initiated by pollen transfer from anther to stigma. One of the two sperm cells carried by the pollen grain fertilizes the egg cell in the flower's carpel, giving rise to a fertilized egg cell or zygote. The subsequent developmental transition of the zygote to a multicellular seedling is termed **zygotic embryogenesis**. Zygotic embryos develop through a series of characteristic morphological stages, in dicotyledonous plants, the globular, heart, torpedo, and bent-cotyledon stages progress to the seedling, which then grows on to an intact plant. Two other forms of embryogenesis, gametic and somatic, analogous to the normal pathway of zygotic development can be induced *in vitro*, and have wide implications and applications in basic and fundamental studies.

Figure 1 High efficiency production of somatic embryos from internodal explant of potato cultivar "Desiree"

Somatic embryogenesis refers to the initiation of embryos from previously differentiated somatic cells. This relies on the reprogramming of gene expression and triggers many structural changes which are similar to those found in normal, zygotic embryos. This system of regeneration has only recently been unequivocally demonstrated in potato[1]. Tissue explants of potato cultivar "Desiree" were induced, using a three stage (maintenance – induction – expression) protocol, to form somatic embryos at a high rate of efficiency (Fig. 1). Confirmation of the progression of

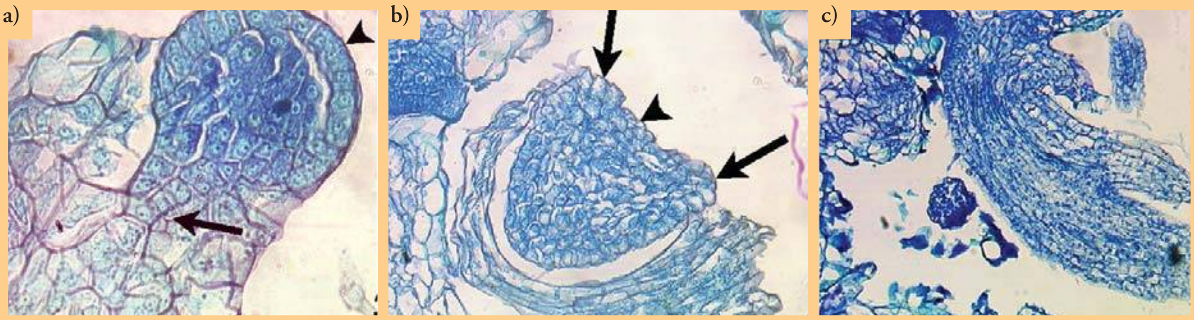


Figure 2 Developmental stages of somatic embryogenesis of potato cultivar "Desiree" : **a)** globular embryo with visible protoderm (arrowhead) and a suspensor-like-structure (arrow); **b)** heart shaped somatic embryo containing cotyledonary initials (arrows) and differentiating apical meristem region (arrow head); **c)** torpedo stage embryo.

[a] MTT Agrifood Research Finland, Plant Production Research, Crops and Biotechnology, Myllytie 10, FIN-31600, Jokioinen, Finland.

Figure 3 Developing embryos from anthers of potato cultivar Pito.

somatic embryogenesis through each of the characteristic stages (corresponding to the developmental stages observed in zygotic embryogenesis) was performed by a detailed histological analysis (Fig. 2). Specific patterns of gene expression at each developmental stage are currently being investigated.

In **gametic embryogenesis** the development of a gametic cell, which is haploid (n), having half the genetic constitution of the parent plant, is diverted to produce embryos, rather than mature pollen grains or ovules. In the case of microspores (cells destined to become pollen) there is the potential to produce several hundred plants from a single isolated anther. Following on from this stage, induced or spontaneous doubling of the haploid cells produces doubled haploid (2n) plants. These plants are theoretically homozygous, true breeding and are of significance in plant breeding either as parental lines or as finished varieties. Though the techniques work well in several species such as barley and Brassica napus, there have only been limited reports of the uptake of this strategy in potato to date. We have recently adapted a method[2] for the high efficiency regeneration of di-haploid material from anthers/microspores (Fig. 3), of the potato cultivar "Pito" and are expanding this to other cultivars.

In addition to model systems for understanding the processes involved in embryo development, both somatic and gametic embryos may be used as an efficient method for the propagation of large numbers of clonal individuals of valuable lines. We have the capacity to exploit the unique portfolio of vegetative regeneration pathways in potato for a wide range of applications in basic science (gene expression; genetic mapping; haplotyping and other fundamental tools) and for end-user applications in the development and rapid clonal propagation of novel plant material

References

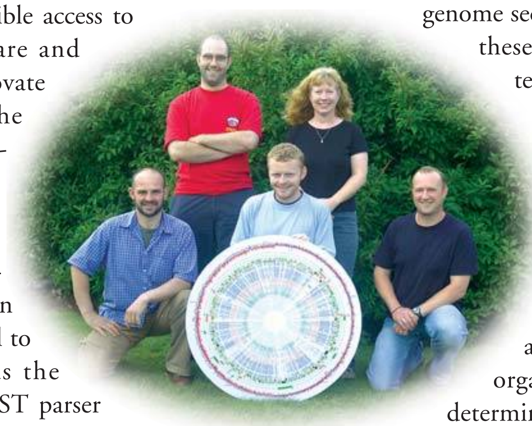
[1]Sharma, SK and Millam, S (2004). *Plant Cell Reports* **23**, 115-119

[2]Rokka VM, Pietila L, Pehu E (1996) *American Potato Journal* **73**, 1-12

Bioinformatics in Plant Pathology

L. Pritchard, J.A. White, S.C. Whisson, I.K. Toth & P.R.J. Birch

The way biology is carried out has been changed forever by the recent explosion in genome sequences, and modern post-genomic and high-throughput experimental techniques which have the capacity to bring an unprecedented quantity of information to practically any biological field. Mathematical approaches to biology have acquired great value to biologists, and otherwise unattainable insights now flow regularly from computational techniques. These approaches require a blend of biological and computational expertise, flexible access to appropriate computing hardware and facilities, and the ability to innovate freely at the cutting edge of the emerging discipline of bioinformatics.



The Plant-Pathogen Interactions (PPI) bioinformatics team continues to contribute to the BioPython project and to develop tools useful to the wider community, such as the *PyZerg* wrapper to the *Zerg* BLAST parser and the *GenomeDiagram* programming library, which was integral to the comparative genomics analyses of *Erwinia carotovora* subsp. *atroseptica* (*Eca*). *GenomeDiagram* (Fig. 1) is a free drawing package that allows the user to generate publication-quality graphics of their genome or biological sequence data, which has been downloaded worldwide and is finding use in the ongoing *Clavibacter michiganensis* sequencing study at Colorado State University.

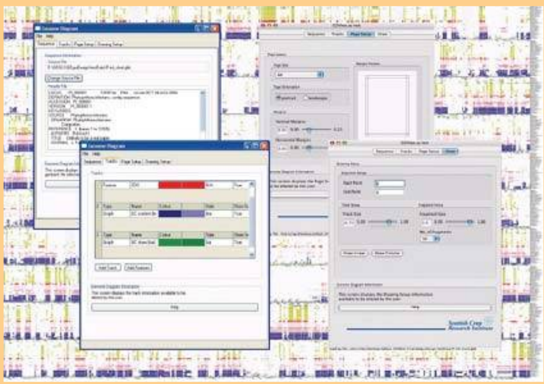


Figure 1 GenomeDiagram output and graphical interface screenshots from OS X and Windows XP.

In PPI, the *Erwinia* and *Phytophthora* groups in particular have generated large amounts of sequence data, typical of biology in this genomic era, and the *Eca* bacterial genome[1] has been sequenced by SCRI in collaboration with the Sanger Institute. Comparative genomics analyses of *Eca* and all other available bacterial genomes suggest that many of the disease-causing characteristics of *Eca* 'jumped' into this pathogen from other bacteria[1]. For *Pi*, DNA sequence databases comprising tens of thousands of ESTs and partial genome sequences are available, and with these data the PPI bioinformatics team has located and investigated regions of similarity between the oomycetes *Pi* and *Hyaloperonospora parasitica* (in collaboration with Warwick HRI). This revealed, surprisingly, that gene synteny is conserved at a key region in each of these organisms that is responsible for determining whether infection occurs on host plants. A pipeline for the identification of Short Interspersed Elements (SINEs) in genomic sequences was also developed and applied to *Pi*, further characterising the pathogen and its evolution.

PPI have designed and are currently using custom Agilent microarrays that contain probes for the complete set of *Eca* coding sequences and selected potato sequences, and the groups also have access to results from the *Pi* Affymetrix microarrays *via* the Syngenta *Phytophthora* Consortium. These arrays, and the bioinformatic approaches described above, have great potential to improve our understanding of what goes on at a fundamental level in the pathogens themselves, and in their interactions with host plants as disease progresses.

References

[1]Bell, K.S., Sebaihia, M., Pritchard, L., Holden, M.T.G., Hyman, L.J., Holeva, M.C., Thomson, N.R., Bentley, S.D., Churcher, L.J.C., Mungall, K., Atkin, R., Bason, N., Brooks, K., Chillingworth, T., Clark, K., Doggett, J., Fraser, A., Hance, Z., Hauser, H., Jagels, K., Moule, S., Norbertczak, H., Ormond, D., Price, C., Quail, M.A., Sanders, M., Walker, D., Whitehead, S., Salmond, G.P.C., Birch, P.R.J., Parkhill J. & Toth, I.K. (2004). *Proceedings of the National Academy of Sciences of the USA* **101**, 11105-11110.

Functional genomics tools for the major eukaryotic pathogens of potato

S.C. Whisson, A.O. Avrova, P.R.J. Birch, M. Adam, V.C. Blok & J.T. Jones

The greatest losses from disease in potato crops are caused by the independent actions of the oomycete *Phytophthora infestans* causing late blight, and the potato cyst nematodes (PCN) *Globodera pallida* and *G. rostochiensis*. Compared with viruses and bacteria, these eukaryotic pathogens have complex life cycles and genetics, and large genomes. Although PCN and *P. infestans* use very different strategies to invade host plants, both establish intimate interactions within the invaded plant tissues. Much research on both pathogens to date has focussed on discovering genes that are specifically up-regulated during their interactions with potato. This has led to the identification of numerous genes that are potentially important in establishing or maintaining a compatible interaction (disease). However, many of the newly discovered pathogen genes are unique and it is difficult to infer any function from sequence alone. A strategy for determining the function of these novel genes is therefore needed.

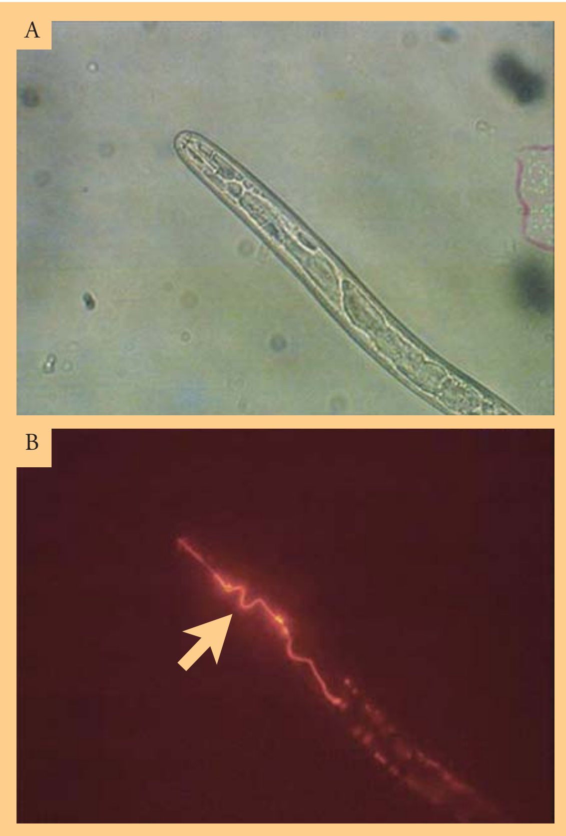


Figure 1 Uptake of dsRNA labelled with Cy3 by a *G. pallida* second stage juvenile. A- bright field image. B- same nematode viewed under fluorescence optics. Labelled dsRNA is visible in the tube that connects the nematode stylet to the digestive system (arrow).

One of the most revealing ways to analyse gene function is to remove its activity through gene silencing. RNA interference (RNAi) has been widely exploited in many organisms as a strategy for determining gene function through silencing. RNAi relies on the degradation of gene-specific double-stranded RNA (dsRNA) molecules into short interfering RNAs (siRNAs) that guide the destruction of the identical endogenous messenger RNA from the gene of interest. RNAi has not been widely applied in determining gene function in eukaryotic plant pathogens. At SCRI, RNAi has been successfully adapted for use in determining gene function in the nematode *G. pallida* (Fig. 1), an organism that has previously been recalcitrant to analysis of gene function. The function of genes potentially involved in sensory perception, invasion and avirulence is currently being studied.

Most recently, RNAi has been adapted at SCRI for use in *P. infestans*. Protoplasts derived from mycelium have been shown to take up dsRNA and exhibit RNAi gene silencing as the mycelium regenerates (Fig. 2A, 2B). dsRNA also triggers a secondary down-regulation

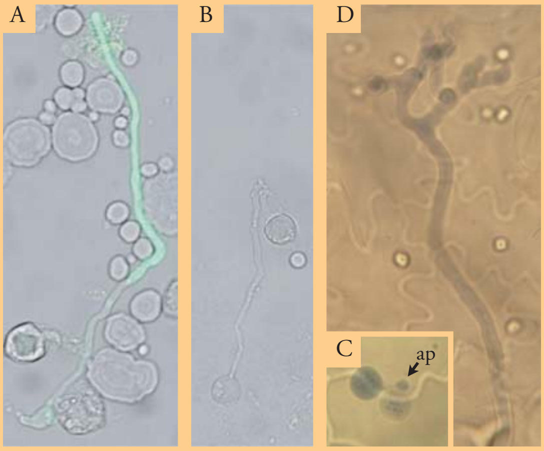


Figure 2 Treatment of transgenic *P. infestans* protoplasts expressing green fluorescent protein (GFP) (A) with *gfp*-dsRNA results in silencing of the *gfp* gene (B) in regenerating protoplasts. Silencing of a *P. infestans* gene expressed in germinating cysts with appressoria (ap arrowed) during the early stages of infection (C) results in abnormal cyst germination and no appressorium formation (D).

of the target gene in *P. infestans* approximately 12 – 15 days after exposure to dsRNA. The mechanism causing this is presently unknown but is being investigated. The significance of this is that it allows the effect of silencing specific genes on all lifecycle stages, including infection, to be investigated. Several *P. infestans* genes have already been studied at SCRI using RNAi. Of these, a striking phenotype was observed with an entirely novel gene that has been shown to be up-regulated prior to invasion, and during the late stages of infection. Silencing of this gene prevented formation of preinfection structures called appressoria, and reduced invasion of potato leaves (Fig 2C, 2D).

Genes that are specific to individual pathogens or groups of pathogens are promising areas for future disease control strategies. However, proof of the role of these genes and their encoded proteins in disease is a crucial requirement. Additional genes will be tested in future to reveal a more complete picture of nematode and oomycete pathogen biology, and provide targets for future control strategies.

Real time studies of cell-to-cell communication

P. Boevink, J. Calcutt, A.G. Roberts & K.J. Oparka

Effective co-ordination of the growth and behaviour of plant cells is essential for normal development. The main effectors of this co-ordination are a wide variety of signalling molecules, such as ions, sugars, RNAs, proteins and metabolites. A major pathway for the transmission of such signalling molecules from cell to cell is through plasmodesmata, complex, membrane-lined channels that connect most plant cells with their neighbours. Signal transmission through plasmodesmata is potentially very rapid and direct as both the endoplasmic reticulum (ER) and cytoplasm are continuous between cells through their plasmodesmata. Plasmodesmata, however, are not open pipes through which molecules flow freely. Instead, they are filled with proteins and cytoskeletal structures, and their openings are often constricted. Small ions and sugars are thought to diffuse through plasmodesmata, but how do the larger molecules such as RNAs and proteins pass through?

Both electron microscopy tissue preparation and microinjection techniques are likely to affect plasmodesmata, as they are very sensitive to changes in the cell, so we cannot be sure that the size exclusion limit (SEL) values determined reflect the natural state. Furthermore, we have very little information on the dynamic properties of plasmodesmata. We do not know whether macromolecular trafficking through plasmodesmata involves a general opening of the channel (gating) or might, in addition, require chaperone proteins. The use of fluorescent proteins has led to many advances in our understanding of plasmodesmal function. We have shown by bombardment of plasmids expressing variously sized fluorescent protein fusions that the SEL of plasmodesmata in sink regions of the plant are much greater than in source regions[1]. These data were not real-time, however, as it takes at least 6 hours for sufficient proteins to be produced in the bombarded cell for it to be detectable. Recently, a new tool has been developed that has overcome this limitation. Photoactivatable GFP (PA-GFP) was developed by Patterson and Lippincott-Schwartz[2]. It is a variant of a bright GFP (EGFP) that is barely fluorescent until activated by a burst of approximately 400 nm wavelength light, after which it becomes highly fluorescent.

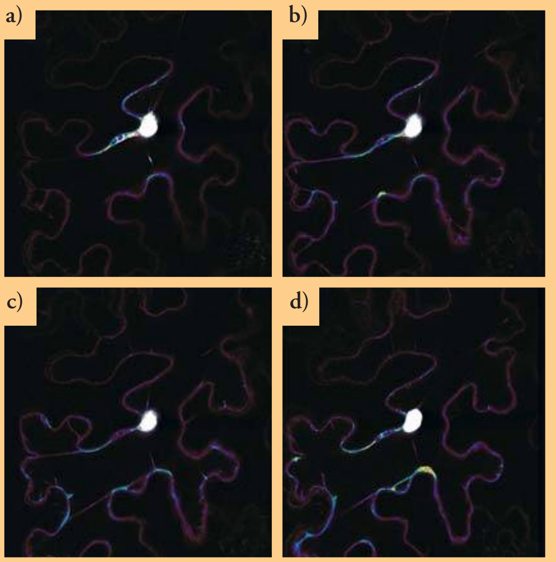


Figure 1 Photoactivation and spread of PA-GFP within a cell. An area within the nucleus of this large, mature *Nicotiana* epidermal cell was photoactivated and the movement of the activated PA-GFP from the nucleus to the cytoplasm was imaged for 20 scans (about 2 minutes). These four images were taken from that series; (a) was the first image and (d) was the last, (b) and (c) are from within the series, the four images are evenly spread over time. They are false coloured such that the most intense fluorescence appears white while low intensity fluorescence appears purple. The images are single optical sections. All images in this article were taken with a Leica SP2 confocal microscope.

We have expressed PA-GFP transiently in *Nicotiana* species by agroinfiltration, and constitutively in transgenic *Arabidopsis* produced by the floral dipping method. The PA-GFP was activated in the nuclei of expressing cells by single scans of regions of interest (ROIs) at maximal zoom (x32) with 405 nm light from a blue diode laser. Nuclei were chosen because they contain high concentrations of fluorescent protein, allowing more accurate activation of individual cells. Activated PA-GFP moved out of the nucleus into the cytoplasm almost instantly and then became rapidly distributed throughout the cell (Fig. 1). Extensive movement of PA-GFP from activated cells on the smallest agroinfiltratable leaves was observed, but it was restricted to the activated cell in the majority of mature source leaves. Interestingly some mature cells did allow movement of PA-GFP into one or two neighbouring cells (Fig. 2a). This suggests that at any one time the plasmodesmata linking mature cells may be gated (have increased SELs) to allow free exchange of information. Movement was most commonly observed into and out of subsidiary cells adjacent to stomata.

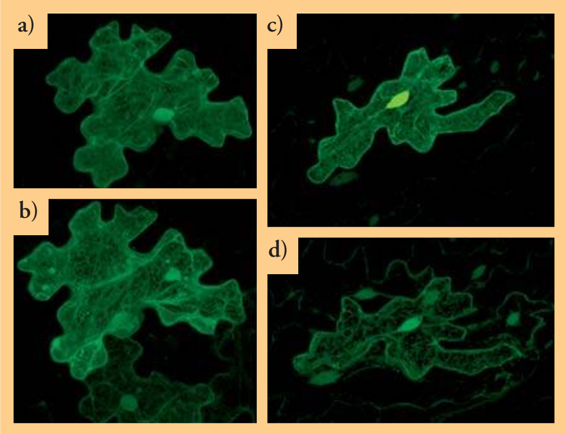


Figure 2 Movement of PA-GFP in mature *Nicotiana* and *Arabidopsis* leaves. An epidermal cell on a *Nicotiana tabacum* large source leaf a couple of minutes after activation (a) and 21 hours later (b). Some movement of the fluorophore has occurred into two cells abutting the activated cell (in the lower half of the image in b) but not into all adjacent cells. In contrast the PA-GFP activated in this apparently mature *Arabidopsis* epidermal cell (c) has moved into all surrounding cells in 6 hours (d). Images are composed of serial optical sections.

The results of activation of PA-GFP in the transgenic *Arabidopsis* leaves suggest that the sink-source transition pattern is very different from that in *Nicotiana* species. *Arabidopsis* leaf cells appear more 'leaky', that is the activated PA-GFP moves extensively within an hour, even on apparently mature leaves (Fig. 2b). Unlike constitutively fluorescent proteins, PA-GFP allows the movement of the protein from activated cells to be quantified. Measurement of the PA-GFP fluorescence in symplastically isolated guard cells confirmed that there was no movement on PA-GFP when plasmodesmatal connections were absent, and revealed a slow degradation of the PA-GFP of around 16% in 18 hours. This latter result suggests another use for PA-GFP, namely in the analysis of protein degradation within plant cells. A protein of interest could be

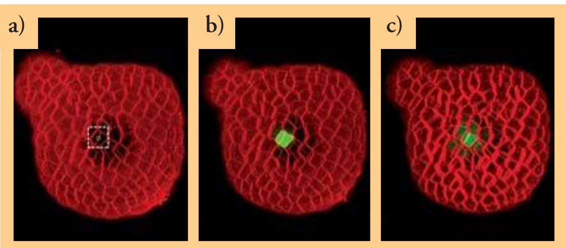


Figure 3 Photoactivation in *Arabidopsis* shoot meristems. A single cell at the top of a shoot apical meristem was phoactivated by scanning the area within the green circle shown in (a) at maximum zoom, the broken white line indicates the maximum zoom. An image was taken immediately after activation (b) and again after 2 hours (c). The fluorescence from the activated cell has diffused into surrounding cells. Images are composed of serial optical sections.

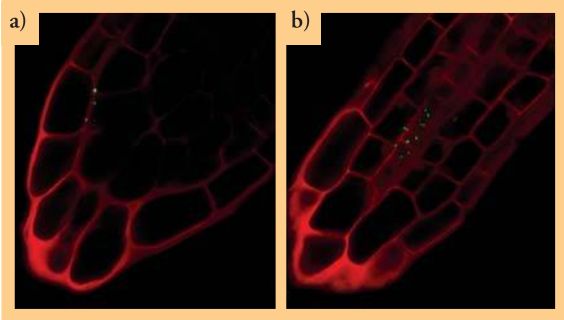


Figure 4 30K-PAGFP activation in roots. Activation of 30K-PAGFP in plasmodesmata of individual side (a) and facing (b) walls in two *Arabidopsis* roots. Images are single optical sections.

fused to PA-GFP, activated, and the kinetics of degradation determined in real time by measuring the loss of fluorescence.

Signal exchange between cells in meristems is essential for normal development of plant tissues. Transcription factors that regulate development, such as Knotted-1, are thought to move between specific cell layers in the meristem via plasmodesmata. PA-GFP transgenic *Arabidopsis* will provide us with the first opportunity to study macromolecular trafficking in meristems non-invasively and in real time. In preliminary work PA-GFP has been activated in specific cells in root and shoot meristems (Fig. 3).

A crucial factor in the ability of molecules to move through plasmodesmata lies in the structure of the plasmodesmal pore. Simple plasmodesmata, which are predominantly found in immature tissues, have significantly greater SELs than branched plasmodesmata. The 30K movement protein from TMV is a useful tool for monitoring the development of plasmodesmata. The 30K protein only accumulates (as a fluorescent protein fusion) in branched plasmodesmata. We have generated transgenic *Arabidopsis* expressing the 30K protein fused to PA-GFP (Fig. 4). Activation of fluorescence in specific plasmodesmata in dividing cells will allow us to monitor changes in the locations of plasmodesmata during and after cell division.

PA-GFP, the first robust activatable fluorescent protein has great potential for non-invasive studies of intercellular communication in plants and will also be a powerful tool for studies of intracellular protein dynamics.

References

[1]Oparka, K.J., Roberts, A.G., Boevink, P., Santa Cruz, S., Roberts, I.M., Pradel, K.S., Imlau, A., Kotlizky, G., Sauer, N., & Epel, B. (1999) *Cell* 97, 743-754

[2]Patterson, G.H. & Lippincott-Schwartz, J. (2002) *Science* **297**, 1873-1877

In search of plant Golgi matrix proteins

M. Latijnhouwers, P. Boevink, C. Hawes[a] & K.J. Oparka

In our modern world, we rely on the efficient transport of goods for our everyday needs. Road blocks that stop traffic between cities turn the country into chaos and our lives upside down. Just as in our own society, transport of materials from one location in the plant cell to another is absolutely essential for normal cell functions.

Every single protein that is synthesised within the cytoplasm needs to find its way to the location where it will carry out its function. The information that tells a protein where to go is often encoded in the shape of that protein. In plant cells, proteins may be 'addressed' to the outside of the cell (secretion), to protein bodies (for storage) or to various organelles such as the vacuole, chloroplasts, mitochondria and peroxisomes. For many of these proteins, the journey to their final destinations starts at the endoplasmic reticulum (ER), a three dimensional network of tubules that forms the basis of the protein sorting machinery. The address label ('post code') of this class of proteins is a small sequence at the beginning of the protein called a signal peptide. Each newly synthesised protein that contains a signal peptide is directly guided into the ER. Extensive sorting of the proteins in the ER results in the selection of a subset that is destined for the extracellular space or the vacuoles. This subset of proteins is sent to a second major processing centre, the Golgi apparatus.

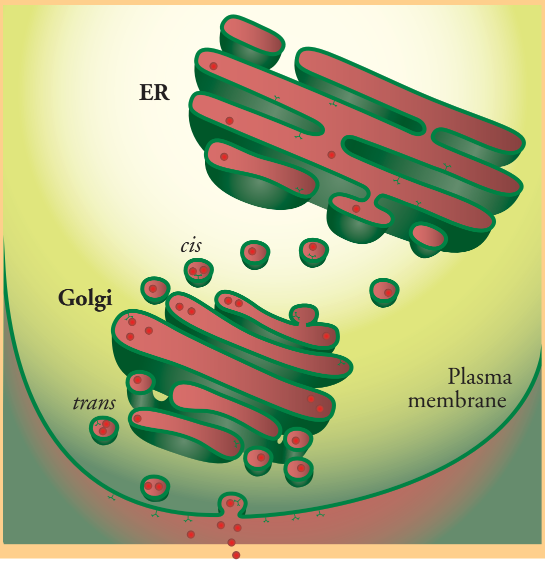


Figure 1 Diagram illustrating the relationship between the ER and the Golgi apparatus. Vesicle movement is shown transporting proteins from the ER to the Golgi stack and from the Golgi to the plasma membrane.

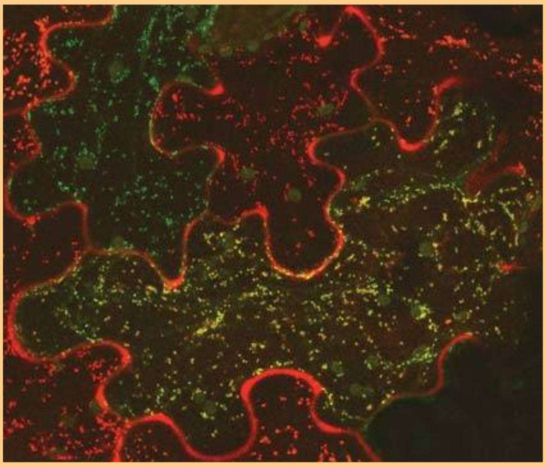


Figure 2 *Nicotiana tabacum* epidermal cells expressing the *trans*-membrane domain of sialyl-transferase fused to the red-fluorescent protein (ST-mRFP; a Golgi marker) and AtGRIP fused to the green-fluorescent protein (GFP). Some cells express only ST-mRFP or the AtGRIP-GFP fusion protein, resulting in cells with either purely red or purely green Golgi stacks. The cell in the lower centre of the picture expresses both markers. Co-localisation of the red and the green fluorescent proteins appears yellow.

The Golgi apparatus consists of stacks of cisternae that are like large, flat vesicles. One of the functions of the Golgi apparatus is the glycosylation of proteins (modification by addition of sugar groups). The Golgi cisternae contain the enzymes that catalyse this glycosylation. Proteins enter the Golgi on the *cis* side and travel through the Golgi until they reach the *trans* side. Transport to and from the cisternae is carried out by means of small vesicles that pinch off from one cisterna and fuse to the next. From the *trans* Golgi, the proteins are sent within vesicles to their destinations, the plasma membrane or the vacuole. In animal cells, the Golgi stacks aggregate around the nucleus. They disintegrate during mitosis and reform afterwards. In contrast, in plants the Golgi stacks are dispersed throughout the cytosol and move with or along the ER. They remain intact throughout mitosis. The molecular basis and the purpose of the differences

[a] School of Biological and Molecular Sciences, Oxford Brookes University, Headington, Oxford OX3 0BP

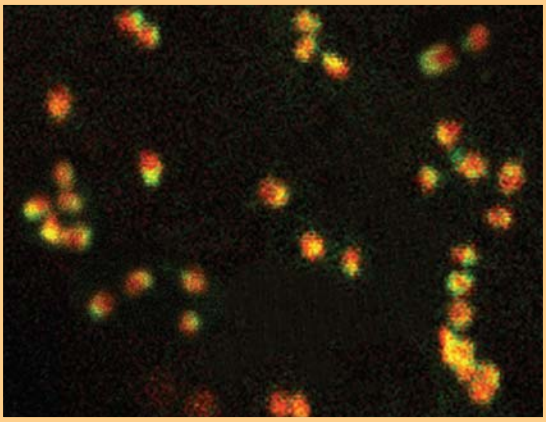
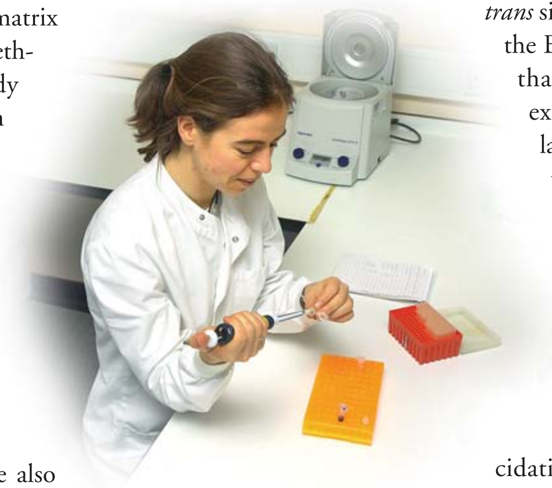


Figure 3 Magnification of individual Golgi stacks with both the red Golgi marker (ST-mRFP) and the green fluorescing AtGRIP-GFP. Note that the red marker labels the entire Golgi stack and shows them as round bodies whereas the green AtGRIP locates to one end of each stack.

between animal and plant Golgi is unknown and is an intriguing question that we are trying to address.

In the last few years, a large number of proteins from animal Golgi stacks have been characterised that give structural support to the Golgi. They are involved in the stacking of cisternae and in binding (tethering) of vesicles to their destination membranes in the Golgi. These proteins are called **Golgi matrix proteins** and are found to be components of a proteinaceous matrix linking Golgi cisternae together. This matrix had already been noticed in electron microscopy studies. The Golgi matrix proteins are generally large proteins containing long coiled-coil domains that form rod-like structures. These domains are commonly found in structural proteins.



Although plant Golgi were also found to have a proteinaceous matrix around them, its composition is unknown, as is how the Golgi stacks are held together as they move around the cell. To find plant Golgi matrix proteins, we used the BLAST programme to compare animal Golgi matrix proteins to the protein sequences from the model plant *Arabidopsis thaliana*. In this way, an *Arabidopsis* protein was identified possessing a feature called a 'GRIP domain'. This protein domain has been found in a number of animal and yeast Golgi matrix proteins. Apart from the GRIP domain, the *Arabidopsis* protein shows extensive coiled-coil regions. The protein was christened AtGRIP (*Arabidopsis thaliana* GRIP domain protein). We expressed AtGRIP as a fusion with the Green Fluorescent Protein (GFP) in tobacco epidermal cells. The tobacco line used for this study stably expresses a red fluorescent marker protein in Golgi stacks. When observed using a fluorescence or confocal laser-scanning microscope (CLSM), the Golgi stacks light up in a bright red colour. In epidermal cells expressing both the red Golgi marker and the AtGRIP-GFP fusion, Golgi stacks contained both red and green fluorescence. When we magnified individual Golgi stacks, we noticed that the AtGRIP-GFP fusion protein was located to one end of the Golgi stack, forming a sort of cap on the round, red dots. This clearly shows that AtGRIP is a Golgi protein. Judging from its structure and domains, we can confidently say that it is a Golgi matrix protein, the first plant Golgi matrix protein to be discovered.

If plant cells are treated with a drug called Brefeldin A (BFA), Golgi stacks disintegrate instantly. Most Golgi proteins are retrieved into the ER. However, it has been shown that proteins residing on the *trans* side of the Golgi do not go back into the ER but instead aggregate into bodies that move in the cytoplasm. This is exactly what happened to the GFP-labelled AtGRIP when the cells were treated with BFA. The green fluorescence aggregated into spots that were clearly larger than Golgi stacks, and the aggregates moved throughout the cell. This suggests that AtGRIP is located on the *trans* side of the Golgi.

Further research will focus on elucidating the role of AtGRIP in protein trafficking, and trying to identify new proteins that interact with AtGRIP. In addition, we are continuing our search for other plant Golgi matrix proteins. All of this is aimed at obtaining a better understanding of how the plant Golgi apparatus controls protein trafficking and secretion in plant cells.

Virus proteins take the endocytic path

S. Haupt, G.H. Cowan, A. Ziegler, A.G. Roberts, K.J. Oparka & L. Torrance

Many plant viruses exploit a unique triplet of proteins known as the triple gene block (TGB) of movement proteins to facilitate virus spread and establish a systemic infection in the host plant. The three proteins work together to transport the virus RNA from the initial infected cell, through surrounding cells to the vascular system for translocation throughout the plant. Although some information is available on the relative roles of the TGB proteins, for example TGB1 binds RNA and is thought to form the viral ribonucleoprotein (vRNP) complex, and TGB2 & 3 are integral membrane proteins that assist transportation of the vRNP, the molecular details of the processes are not well understood. We have used a combination of molecular and cell biology tools to try to dissect the mechanisms involved. Two TGB proteins (TGB2 and TGB3) of *Potato mop-top virus* (PMTV) were expressed as N-terminal fusions to green fluorescent protein (GFP) or monomeric red fluorescent protein (mRFP) in epidermal cells of plants. Some of the plants we used were modified so that organelles such as endoplasmic reticulum, actin filaments, microtubules, plasmodesmata and Golgi were labelled with GFP. We used fluorescent markers and chemical inhibitor treatments to investigate the roles of the different organelles and the cytoskeleton

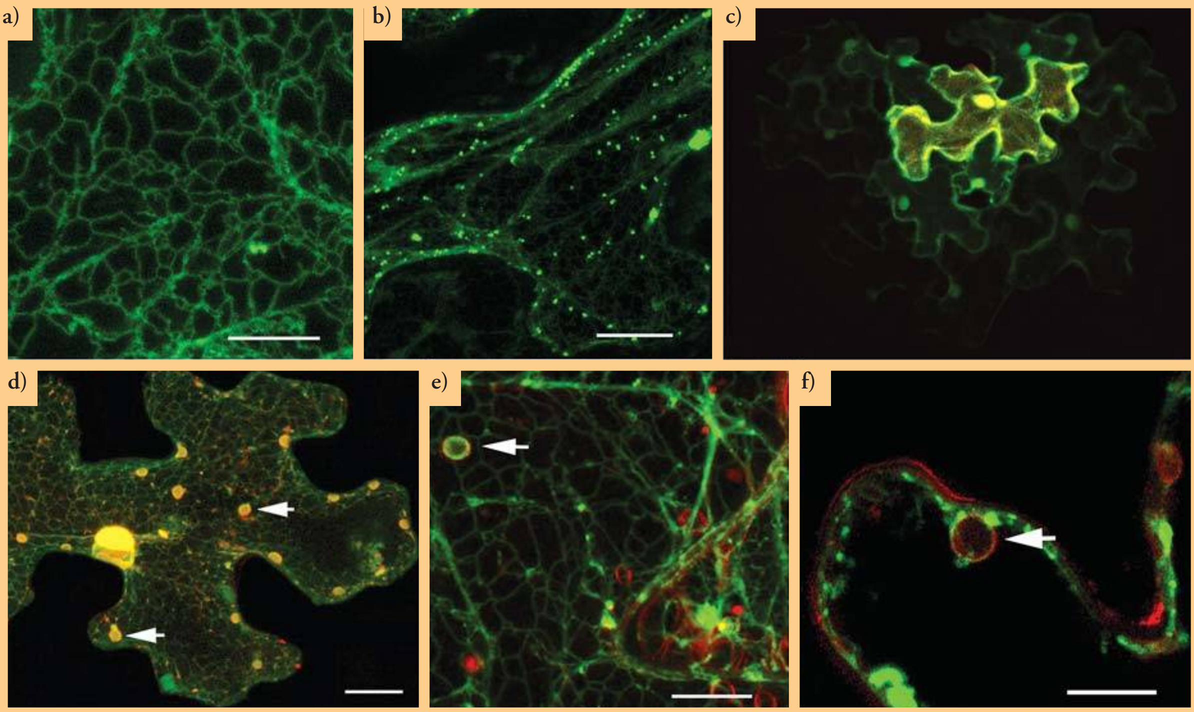


Figure 1 **a)** Transient expression of GFP-TGB2 in epidermal cells of *Nicotiana benthamiana.* Note green fluorescence is prominent in cortical endoplasmic reticulum (ER). Leaves were bombarded with a plasmid expressing GFP-TGB under the control of a 35S promoter (P_{35S}). **b)** Same cells as (a) later in expression; after appearance of green fluorescence in the cortical ER, it is also visible as small motile granules that move quickly at or on the ER network. **c)** Experiments to monitor size exclusion limits (SEL) of plasmodesmata (PD). Leaves were bombarded with a mixture of the plasmids P_{35S}–GFP-sporamin and P_{35S} – mRFP-TGB3. In these and similar experiments with RFP-TGB2, the green fluorescence moved from the initial source cell to neighbouring cells indicating that both TGB proteins increased SEL of PD. No movement of GFP out of source cell was seen in control experiments bombarding cells with P_{35S}–GFP-Sporamin and P_{35S}–mRFP. **d)** Co-localisation of mRFP-TGB2 and GFP-TGB3 in same *N. benthamiana* epidermal cell. Note that GFP-TGB3 appears in ER and together with mRFP-TGB2 in the membranes of the vesicles. At this point in the expression cycle the appearance of mRFP-TGB2 in ER is more patchy. **e)** Co-localisation of FM4-64 and GFP-TGB2; *N. benthamiana* cells were bombarded with P_{35S-}–GFP-TGB2 and infiltrated with FM4-64 dye. **f)** Co-localisation of GFP-Ara7 and mRFP-TGB2; *N. benthamiana* cells were co-bombarded with P_{35S-}–mRFP-TGB2 and P_{35S-}–GFP-Ara7.

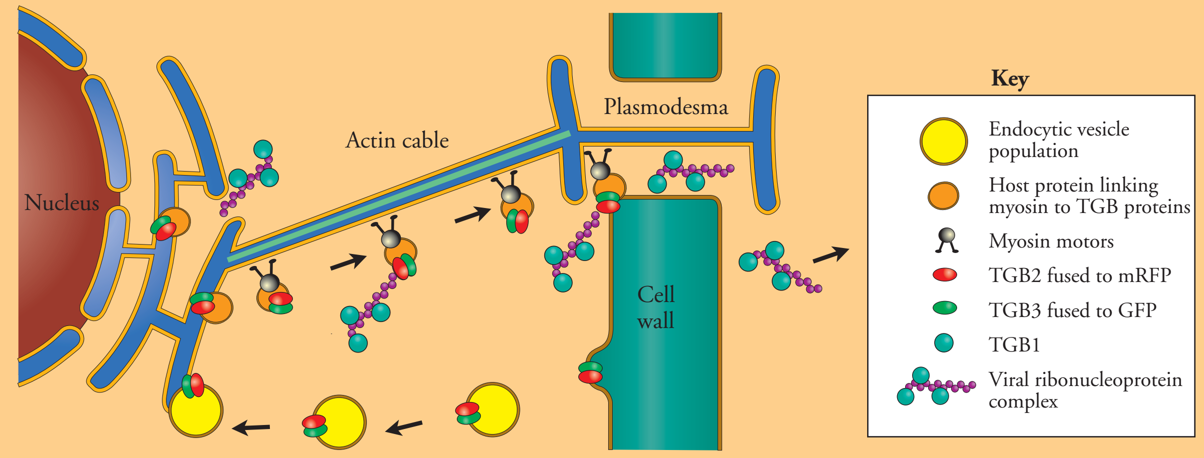


Figure 2 Model indicating the roles of the TGB2 and TGB3 in intracellular movement of PMTV vRNP.

in TGB movement. The fluorescent TGB proteins were visualised in living plant cells using the confocal laser scanning microscope.

These studies revealed that TGB2 and TGB3 fusion proteins associate in small motile granular structures that utilise the endoplasmic reticulum-actin network (Fig. 1a and b) to move quickly to the cell periphery, where they target plasmodesmata. Both TGB2 and TGB3 fusion proteins increased the size exclusion limit of plasmodesmata (Fig. 1c), and fluorophore-labelled TGB3 accumulated at plasmodesmata in the absence of TGB2, suggesting that its primary function is to target plasmodesmata during virus infection. Later, post-targeting of plasmodesmata, both TGB2 and TGB3 fusion proteins were incorporated into vesicular structures (Fig. 1d). TGB2 fusion protein associated with these structures on its own, but the TGB3 fusion protein could not be incorporated into the vesicles in the absence of TGB2. In addition, mRFP-TGB3 was incorporated into vesicles when expressed in PMTV-infected epidermal cells, indicating a cooperation with virus expressed TGB2. FM4-64, a marker for plasma membrane internalisation and components of the endocytic pathway, strongly labelled the TGB fusion protein-containing vesicles (Fig. 1e), while co-localisation of the internalised vesicles with AtRabF2b (Ara7), a Rab5 homologue that marks the early endosome, also implicated the vesicles in the endocytic pathway (Fig. 1f). Protein interaction studies have also revealed that TGB2 interacts with a protein belonging to the RME-8 family of J-domain chaperones, shown recently to be essential for endocytic trafficking in *C. elegans* and *Drosophila*. RME-8 proteins are highly conserved in multicellular organisms from plants to humans, and localise to the limiting membrane of endosomes.

From this work we propose that PMTV TGB2 & 3 associate in membrane bound compartments (probably the small motile granules) and assist transportation of vRNP from sites of RNA replication to the plasmodesmata for transport to neighbouring cells. The TGB2 & 3 do not move from the infected cell but are recycled in the membranes of vesicles derived from the plasma membrane via the endocytic pathway to collect more vRNP (Fig. 2). Future work will aim to show whether the TGB are indeed recycled to the cell interior to resume the trafficking of viral RNA complexes (under control of the virus) or whether they are targeted to the vacuole for subsequent degradation by the plant cell (under control of the host).

References

Haupt, S., Cowan, G.H., Ziegler, A., Roberts, A.G., Oparka, K.J. & Torrance, L. (2005) *The Plant Cell* 17, 164-181

Genes to Products

H.V. Davies & R. Waugh

Within the UK there are clear indications that the transfer of knowledge from model plant systems to crop plants will be a key driver for research funding and product development in the public sector. The SCRI and the Genes to Products Theme are already well positioned to deliver next generation crop plants that fulfill a range of end-user requirements. Multidisciplinary approaches and key strategic alliances (academic and commercial) will be continually fostered to maintain our uniqueness and relevance.

Quality, Health & Nutrition Programme The driving force for the programme is to understand the processes which regulate specific quality and nutritional parameters of our important commodity crops. This combines the skills of natural product chemists, biochemists, molecular biologists and the genetic/breeding skills of the sister programme, Genome Dynamics. Important linkages include those with the University of Dundee Medical School with whom a joint initiative on the nutritional qualities of plant based foods has been established. Metabolite profiling continues to provide an increasingly important technology platform used within the programme, recently assisted by significant grant income from EU Framework VI. Particular attention is focused on the potential to detect unintended effects in GM crops but with a growing remit to understand compositional variability associated with low and high input crop management systems. Thus far metabolite profiling, using potato as a model system, has shown that natural variation (comparisons of varieties and landraces) in the metabolites measured outweighs any differences between GM lines and their appropriate controls. However, it was possible to distinguish specific GM lines from their parents. In addition, there were clear examples of metabolite changes induced in tubers derived from plants generated through tissue culture (non-GM) suggesting that somaclonal variation may represent an important source of unintended effects. Metabolite profiling is also being used to assess associations between raw and processed food quality. For example, increased levels of branched amino acids and methionine in raw potato has been correlated with the production of methional and branched aldehydes, alcohols and esters, reported as key contributors to the characteristic aroma of cooked potato.

Transgenic potato plants have been generated in which the tuber carotenoid content has been enhanced up to 7-fold. Non-transgenic potato germplasm contains negligible amounts of the provitamin A carotenoid, β-carotene, whereas some of the transgenic lines developed contain nutritionally significant levels of β-carotene. Detailed analysis of the potato transgenics (including the use of microarrays and metabolite profiling), is in progress with the aim of understanding how carotenogenesis is regulated. The function of candidate regulatory genes is being assessed using virus-induced gene silencing (VIGs) whilst a protocol for stable transformation has been developed for the normally recalcitrant, high carotenoid-containing diploid species, *S. phureja*. Whilst total carotenoid levels are naturally high within accessions of this species, transgenic approaches have again been successful in increasing the total carotenoid level in tubers by 3- to 4-fold. Collaborations with the Genome Dynamics Programme aim to use association genetics to identify alleles that give rise to high tuber carotenoid levels.

Further progress has been made in understanding how the availability of nutritionally important phytochemicals may be modified in humans. This exploits an *in vitro* digestion model which has shown that the digestion of putatively beneficial soft fruit phenolics is dependent on both ring hydroxylation and glycosylation. Using raspberry fruit, the constituent anthocyanins and ellagitannins were shown to be hydrolysed to small pharmacologically active molecules. Other studies have revealed that specific anthocyanins and ellagitannins inhibit the mammalian starch digestive enzymes α-glucosidase and α-amylase, respectively. This could have direct implications on the availability of simple soluble carbohydrates in the diet.

Genome Dynamics Strategically, biological links between functional, gene-based markers and target phenotypes are being highlighted. For example, genome-wide transcription profiling studies have been used to assemble a collection of ~2,500 barley genes which are responsive to important abiotic stresses by switching on or off. Approximately 1,500 of these genes have been re-sequenced in a number of cultivars revealing differences (single nucleotide polymorphisms or SNPs) which are being used to map them on to the barley genome. In a similar way we are investigating malting quality and yield (see following article by Macaulay *et al.*) and have identified genetic markers associated with hot water extract and epi-heterodendrin production. These markers have potential intellectual property value and will be added to the suite of other markers developed and commercialised by the barley genetics programme.

With regard to barley disease resistance, re-sequencing of the *Mlo* locus (plants carrying loss of function alleles are resistant to all known isolates of powdery mildew) has indicated that the *mlo*-11 allele likely arose just once after barley domestication. Collaboration with the groups of Prof. Paul Shulze-Lefert and Ralph Panstruga (Max Planck Institute, Köln) has shown that resistance is linked to a complex tandem repeat array consisting of 3.5 kb regulatory and 1.1 kb coding sequence inserted upstream of the wild-type gene. It is likely that this array acts as a transcription factor sink leading to *cis*-dependent perturbation of transcription machinery assembly by transcriptional interference. This specific example clearly demonstrates how changes in transcription of a single gene can have a major effect on plant phenotype. A global analysis of genotype-dependent gene expression is described in the following article by Druka *et al.*

Last year we reported that the Commonwealth Potato Collection had been genetically fingerprinted using molecular markers. This year, analysis of the resulting data is providing significant insight into the evolution of the cultivated potato and guiding exploitation through other research programmes at SCRI (see following article by Bryan *et al.*). For example, novel resistance against potato cyst nematode (PCN) and late blight has been identified and is already in the early stages of introgression into the cultivated genepool. Based on the application of molecular markers, the theory of linkage and quantitative trait locus (QTL) analysis, developed at SCRI in collaboration with BioSS, has been successfully applied to the analysis of quantitative resistance to late blight, which remains a potentially devastating disease. This work represents an effective collaboration between geneticists, pathologists and statisticians at SCRI. Along similar lines, a marker linked to the hypersensitive reaction to *Tobacco Rattle Virus* (TRV) the cause of spraing symptoms in the flesh of potato tubers has been identified. A further major gene conferring true resistance to TRV has also been identified.

The new early maincrop potato cultivar Vales Sovereign (superior cooking qualities, good resistance to several important diseases, suitable for Integrated Crop Management production) was added to the National List in 2003 (marketed by Greenvale AP). In addition, a new *Solanum phureja* potato cultivar, Inca Dawn, was also added to the National List in 2003. It is a novelty salad type, with deep yellow flesh colour due to a high carotenoid content and illustrates a clear scientific linkage with the Quality, Health & Nutrition Programme.

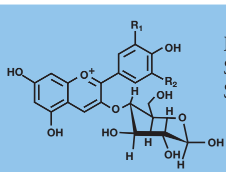
Construction of a genetic linkage map of a target species is considered the entry point into detailed genetical studies and facilitates the identification of markers that can be subsequently used to predict and follow traits in the progeny of crosses between chosen parental lines. The article by Graham *et al.* describes the development and use of the first genetic linkage map of red raspberry. In addition, a publicly available red raspberry BAC library (cultivar Glen Moy) has been developed comprising over 15,000 clones with an average insert size of approximately 130 kb and less than 1% contamination with chloroplast and mitochondrial DNA, respectively. In combination with the mapping studies this library represents the platform for map-based gene isolation in *Rubus*. Linkage mapping in blackcurrants has progressed more slowly, largely due to a lack of polymorphism between the parental lines of the mapping populations and issues with many of the markers that appear to reside in repetitive DNA. Nevertheless, the application of modern breeding technologies remains successful and productive. Blackcurrant cultivars 'Ben Hope' and 'Ben Gairn', the first commercial processing cultivars with resistance to gall mite and reversion virus, respectively, are currently enjoying considerable commercial success throughout Europe, and new seedlings with further improvements in agronomic and quality characters are in final farm-based trials.

Finally, we continue to have significant input into issues related to biodiversity and the erosion of genetic diversity. In collaboration with the Royal Botanic Garden Edinburgh, considerable progress has been made in understanding natural populations of *Koenigia islandica* and *Anastrophyllum joergensenii* and related species through the discovery of molecular polymorphisms. Our observations have led to further work examining a Scottish liverwort population (thought to be *A. joergensenii*) which appears to be a new taxon.

The relevance of soft fruit to human nutrition

D. Stewart, G.J. McDougall & P. Dobson

A recent joint expert report by the World Health Organisation and the Food and Agriculture Organisation of the United Nations concerning the relationship between nutrition and chronic and degenerative diseases concluded that a convincing association exists between the consumption of fruits (including berries) and vegetables and reduced risk of cardiovascular disease (CVD) and cancer. In addition to these epidemiology-based conclusions it is now generally accepted that both of these degenerative diseases are initiated by the oxidative reaction of free radicals with lipids, proteins and DNA within the human body. Logic, therefore, suggests that increased consumption of antioxidants should alleviate, or at least retard, the onset of these diseases and this has been the focus of much research.



Rutinoside – (rhamnosyl-1→6-glucose)
Sophoroside – (glucosyl-1→2-glucose)
Sambubioside – (xylosyl-1→2-glucose)

R_1	R_2	Anthocyanin	Recovery (%)
OH	H	Cyanidin-3-glucoside	61
OH	H	Cyanidin-3-rutinoside	81
OH	H	Cyanidin-3-sambubioside	40
OH	H	Cyanidin-3-sophoroside	85
OH	OH	Delphinidin-3-glucoside	40
OH	OH	Delphinidin-3-rutinoside	59
OH	OH	Delphinidin-3-sambubioside	29
OH	OH	Delphinidin-3-sophoroside	65
OCH_3	OCH_3	Malvidin-3-glucoside	81
OCH_3	OCH_3	Malvidin-3-rutinoside	90
OCH_3	OCH_3	Malvidin-3-sambubioside	55
OCH_3	OCH_3	Malvidin-3-sophoroside	90
H	H	Pelargonidin-3-glucoside	80
H	H	Pelargonidin-3-rutinoside	71
H	H	Pelargonidin-3-sambubioside	35
H	H	Pelargonidin-3-sophoroside	82
OCH_3	H	Peonidin-3-glucoside	49
OCH_3	H	Peonidin-3-rutinoside	75
OCH_3	H	Peonidin-3-sambubioside	80
OCH_3	H	Peonidin-3-sophoroside	81
OCH_3	OH	Petunidin-3-glucoside	40
OCH_3	OH	Petunidin-3-rutinoside	70
OCH_3	OH	Petunidin-3-sambubioside	79
OCH_3	OH	Petunidin-3-sophoroside	72

Table 1 The recoveries of anthocyanins following *in vitro* digestion.

Our previous studies have identified the (sub)classes and diversity of antioxidants present in three soft fruit species relevant to the Scottish economy - *Rubus*, *Ribes* and *Fragaria*. These species are also important sources of nutritional value in Europe and North America along with other species including cloudberry (*Rubus chamaemorus*) and Rowan (*Sorbus spp.*) etc. As bioavailability is a pre-requisite of efficacy in humans we are assessing, using a validated *in vitro* digestion system, the ability of phytochemicals to survive unchanged in transit through the stomach and upper gastrointestinal tract.

LC-MS analyses of *in vitro* digestion products from a range of soft fruit anthocyanins and phenolics showed that resistance to digestion was related to both the degree of methoxylation and glycosylation, as well as the type of glycosylation (Table 1). Without exception, the diglycosylated anthocyanins rutinoside and sophoroside both exhibited greater resistance to *in vitro* digestion than the corresponding mono-glycosylated compounds with the rutinoside generally the more resistant. However the sambubiosides were invariably the least resistant to digestion with the xylose-glucose linkage predominantly responsible for their lability.

The lability of these disaccharide (and, if present, tri-oligosaccharide) linkages does not necessarily compromise nutritional value since degradation of the disaccharide (or oligosaccharide) ultimately leads to the generation, at least transiently, of the mono-glycosylated forms which most likely enter human cells via the intestinal glucose transport (SGLT1) pathway.

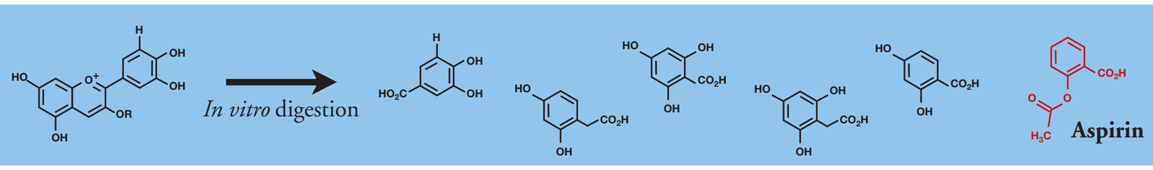


Figure 1 Some of the products produced following the *in vitro* digestion of the anthocyanin cyanidin.

The chemistry of the anthocyanidin moiety itself has a direct bearing on its *in vitro* digestibility. In general, the balance between methoxylation and hydroxylation is directly related to lability to digestion. Malvidin, a dimethoxylated anthocyanin, exhibits the greatest level of resistance to digestion with the tri-hydroxylated anthocyanin, Delphinidin, the least resistant. Interestingly, the progression from tri-, di- to mono-hydroxylation (delphinidin, cyanidin and pelargonidin, respectively) is accompanied by an increasing resistance to digestion for a given glycoside. The analogous progression from di-, mono- to non-methoxylation (malvidin, peonidin and pelargonidin, respectively) is less clear but is broadly related to an increased susceptibility to *in vitro* digestion.

The products of an *in vitro* (and by implication an *in vivo*) digestion process, whilst including aglycones and compounds with reduced levels of glycosylation, also include metabolites with potential pharmacological impact (Fig. 1). Many of these compounds are structurally similar to aspirin, the common anti-inflammatory and pain relief drug which is now prescribed to prevent CVD and strokes. It is estimated that globally, 50 billion aspirin tablets are taken annually. The link between health benefits associated with fruit intake, degenerative diseases and the production of such compounds during digestion warrants further study.

Studies to determine the ability of fruit phenolics to survive *in vitro* digestion showed that differences exist between the species examined, with rowan and lingonberry exhibiting the highest and lowest recoveries, respectively (Fig. 2). The proportion of fruit juice phenols that survived *in vitro* digestion and remained available to reach the 'serum fraction' was generally *c.* 5-10%. However, these values represent a simple digestion model and factors such as active uptake and food-matrix interactions will invariably cause the actual *in vivo* values to be much lower. In addition to this the differences in the polyphenolic composition of the berries will obviously contribute to variations in overall bioavailability of phenolics. However, the model acts as a robust and reproducible way of determining the relative ability of fruit phytochemicals/bioactive compounds to survive the digestive processes.

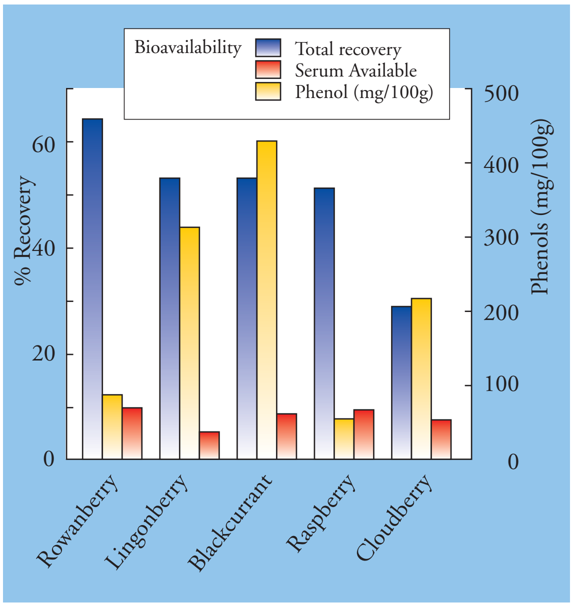


Figure 2 The recoveries and bioavailabilities of selected soft fruit phenolics following *in vitro* digestion. The values are represented as the % of the total phenols recovered or bioavailable to the serum relative to the total phenol added at the start of the *in vitro* digestion, and the absolute sample phenol concentration. The phenol values refer to the total phenol contents of the original juices.

Data from model digestion/bioavailability assessments will be used to test hypotheses on modes of action. This in turn will help drive breeding programmes on nutritional enhancement.

Isoprenoid metabolic networks in potato tubers

M.A. Taylor, L.J.M. Ducreux, W.L. Morris, P.E. Hedley & S. Millam

Isoprenoid biosynthetic pathways provide a wide-range of metabolites that are essential for plant development and storage organ food quality. Examples include the carotenoids which act as photosynthetic pigments and are important micronutrients in storage organs; sterols, essential for membrane function; tocopherols and tocotrienols (vitamin E); chlorophylls that contain a C20 isoprenoid side-chain; the isoprenoid derived phytohormones, gibberellins, brassinosteroids and abscisic acid; and monoterpenes, sesquiterpenes and diterpenes involved in plant defence, aroma and flavour. An understanding of how isoprenoid metabolic networks are regulated is fundamental in the drive to produce plant products of improved quality containing enhanced levels of health-promoting phytochemicals or to manipulate plant developmental processes that are regulated by the levels of the isoprenoid plant hormones.

There has been a rapid escalation in our knowledge of the isoprenoid biosynthetic pathways, particularly at the molecular level. Isoprenoids are synthesised from the 5-carbon intermediates isopentenyl diphosphate and dimethylallyl diphosphate. Although many of the genes encoding the structural enzymes involved in isoprenoid biosynthesis have been cloned, so far only limited data about their integrated regulation have been obtained using classical genetic and biochemical approaches or more recently using a microarray approach in *Arabidopsis*. Additionally, in view of the pace of progress in this area, it is perhaps surprising that the factors that regulate isoprenoid pathways remain to be discovered. This is in contrast to other important metabolic networks such as phenylpropanoid metabolism, where a number of regulatory genes and factors have been described.

Using a metabolic engineering approach, we have attempted to perturb aspects of isoprenoid metabolism in potato tubers. Our aims are to determine the extent to which it is possible to enhance the accumulation of nutritionally important isoprenoids such as carotenoids, and to learn more about the integrated regulation of isoprenoid metabolism. In one example we have produced transgenic potato plants expressing an *Erwinia uredovora crtB* gene encoding phytoene synthase, specifically in the tuber of *Solanum tuberosum* L. cultivar Désirée, which normally produces tubers of low carotenoid content (8.6 µg carotenoid g^{-1} DW) and also in *Solanum phureja* L. DB337 (tuber carotenoid content typically 20 µg carotenoid g^{-1} DW). In developing tubers of transgenic *crtB* Désirée lines, carotenoid levels reached 35 µg carotenoid g^{-1} DW and the balance of carotenoids changed radically compared with controls: β-carotene levels in the transgenic tubers reached *c.* 11 µg g^{-1} DW, whereas control tubers contained negligible amounts and lutein accumulated to a level of 12 µg g^{-1} DW, 20-fold higher than controls (Fig. 1). Following the development of a novel transformation protocol for potato diploids, the *crtB* gene was also transformed into *S. phureja* DB337, and a large increase in total carotenoid content (to 78 µg carotenoid g^{-1} DW) was measured in the most affected transgenic line. In these tubers, the major carotenoids were violaxanthin, lutein, antheraxanthin and β-carotene. No increases in expression levels of the major carotenoid biosynthetic genes could be detected in the transgenic tubers, despite the large increase in carotenoid accumulation. Thus by over-expressing the *crtB* gene, we can produce potato tubers containing carotenoids not normally found at significant levels in potato germplasm (β-carotene). This finding is of particular importance as β-carotene is the major provitamin A carotenoid and the levels found in tubers from the best transgenic lines could contribute significantly to the dietary vitamin A requirement. On a dry weight basis, the β-carotene content of *crtB* tubers is up to 7-fold greater than that of the highest published value for 'Golden rice'.

Having successfully perturbed isoprenoid metabolism, we applied a combined isoprenoid and transcript profiling approach to gain further insights into the regulatory mechanisms that control isoprenoid levels. Microarray analysis was used to identify a number of genes that were consistently up or down-regulated in transgenic *crtB* tubers. We are currently using a gene silencing approach to investigate further the roles of these candidate genes. In collaboration with the Cell-to-Cell Communication Programme we previously demonstrated that a modified potato virus X vector could be used to silence gene expression in potato leaves and tubers and we are exploiting this approach in our study of the candidate genes revealed by microarray analysis. Over-expression of other carotenoid biosyn-

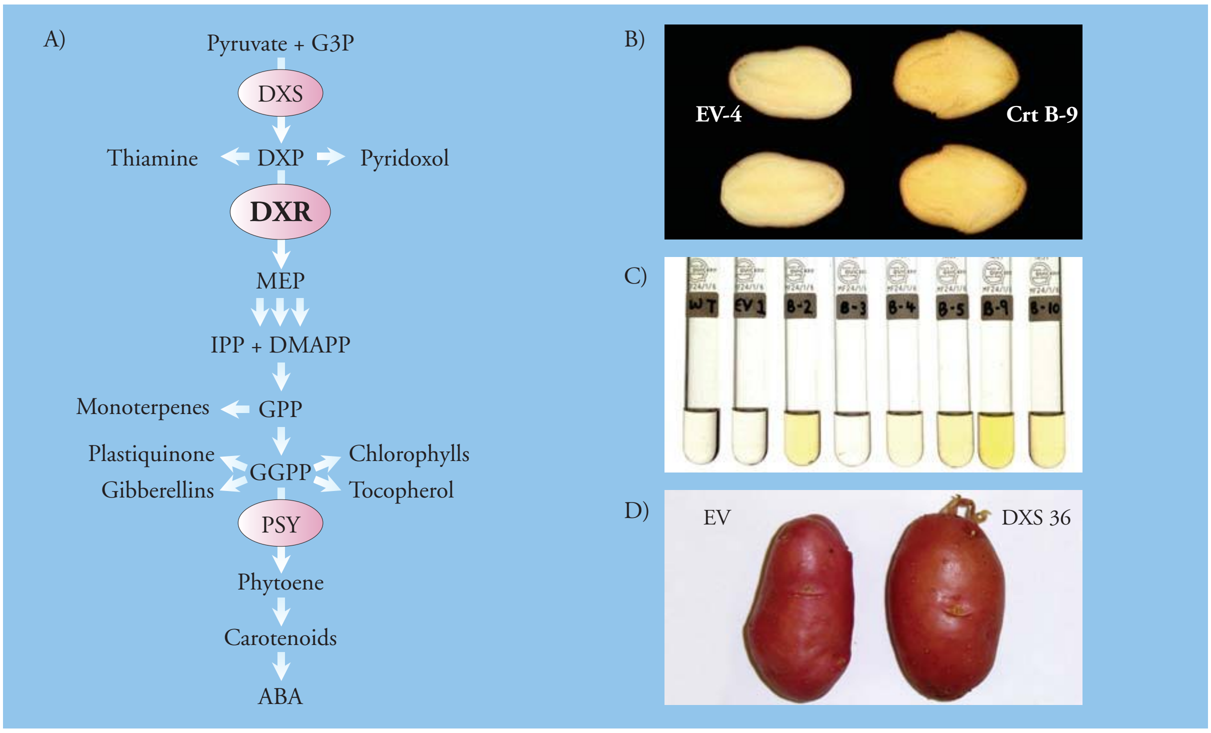


Figure 1 A) The biochemical pathway of isoprenoid metabolism in the plastid. B) Mature tubers of *S. tuberosum* cv. Désirée expressing the *Erwinia uredovora crtB* gene (crtB-9) compared with controls (Ev-4). C) Solvent extracts of carotenoids from transgenic tubers expressing *crtB*. D) Transgenic tubers at harvest, expressing a bacterial 1-deoxy-D-xylulose 5-phosphate synthase gene (DXS36) compared with control (EV).

thetic genes has also led to the accumulation of carotenoids not normally found in potato tubers. For example, tuber-specific expression of an algal ketolase gene (*crtO*) leads to the accumulation of the carotenoid astaxanthin, increasingly being marketed as a neutraceutical because of an array of health benefits associated with its consumption. We are currently exploring techniques for introducing several transgenes simultaneously into potato (co-transformation) so that we can increase levels of accumulation further.

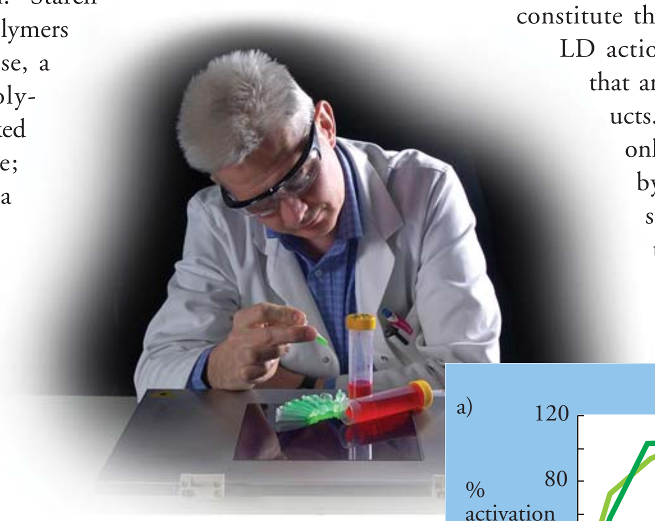
In another example of metabolic engineering we targeted a very early reaction in the biosynthesis of plastidic isoprenoids. Some literature suggests that the first step in the reaction path to isopentenyl pyrophosphate, the acyloin condensation of glyceraldehyde-3-phosphate with pyruvate catalysed by 1-deoxy-D-xylulose 5-phosphate synthase (DXS), limits the rate of carotenoid biosynthesis. Thus we were interested in investigating the effects of over-expressing this enzyme in the tuber plastid. We over-expressed an *E. coli* DXS gene in the plastid of the potato tuber and determined the effects on isoprenoid biosynthesis. No major changes in tuber carotenoid content were detected in developing tubers; however, on harvesting mature tubers we observed that in many of the transgenic lines (approximately 20 out of 40) there was an 'early sprouting' phenotype – many tubers were already sprouting at harvest and in some lines there was a loss of apical dominance (Fig. 1). This is a robust phenotype, the 'severity' of which correlates with the level of expression of the DXS transgene. Interestingly, the early sprouting phenotype is similar to that observed for tubers of many *S. phureja* accessions. We suspect that in these transgenics there are enhanced levels or rates of gibberellin biosynthesis, that is, the increased DXS activity results in flux being driven to isoprenoids other than the carotenoids. These transgenics thus provide an invaluable and unique opportunity to investigate aspects of isoprenoid metabolic control and provide a novel resource with a clear phenotype that impacts on aspects of the tuber life-cycle of commercial importance (tuber sprouting and dormancy).

In summary, our metabolic engineering approach has confirmed that there is considerable flexibility in the types and amounts of nutritionally important isoprenoids that can accumulate in tubers. Additionally we have indications that the control of isoprenoid metabolic flux impacts on important aspects of the tuber life-cycle.

A novel activity for a starch debranching enzyme

G.J. McDougall, H.A. Ross, J.S. Swanston & H.V. Davies

Starch is the major carbohydrate reserve in cereals and is an important source of dietary carbohydrate for humans and animals. Starch from barley is also important to brewers and distillers, as it is hydrolysed to sugars, which are then fermented to alcohol. Starch consists of two polymers of glucose; amylose, a straight chain polymer of α-(1-4) linked chains of glucose; and amylopectin, a polymer of α-(1-4) linked glucose polymer with α-(1-6) linked branch points (Fig. 1). During the germination of cereal grains, the starch reserves are broken down by the action of a battery of enzymes to support the growth of the emerging seedling. However, the α-(1-6) linked branch points can only be broken by the enzyme limit dextrinase (LD). Considering that barley starch consists of 75% amylopectin, debranching by LD is of crucial importance for complete starch degradation. LD activity has been confirmed as a rate limiting step in starch degradation in barley and much research has focused on selecting malting barley varieties with a high expression of LD to maximise fermentable carbohydrate for brewing and distilling[1].



During a study of the activity of LD in malting barleys of differing quality[2], we found that LD was increased by incubation with certain of the sugars that constitute the ultimate digestion products of LD action on starch. It is very unusual that an enzyme is activated by its products. However, this activation could only be detected if LD was measured by particular assays involving the solubilisation (Fig. 2a) or reduction in viscosity of substrates (Fig. 2b) but not if the cleavage events were measured directly (Fig. 2c).

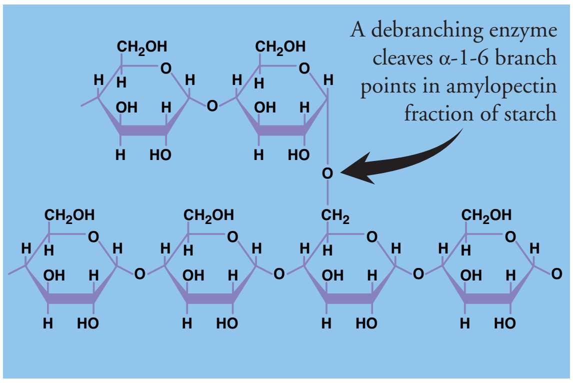


Figure 1 Action of limit dextrinase. LD is solely responsible for the hydrolysis of α-(1-6) branch points of amylopectin.

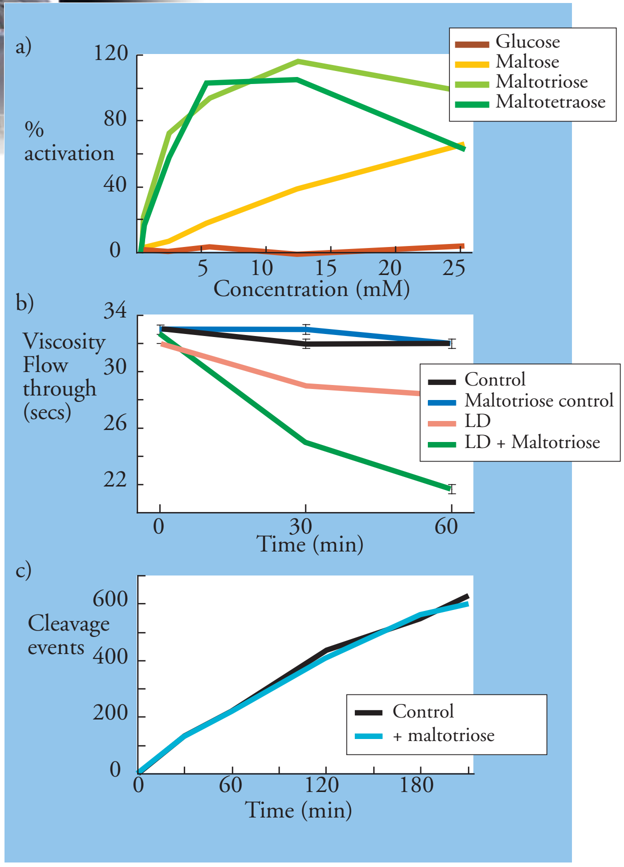


Figure 2 Activation of limit dextrinase by maltodextrins is dependent on the assay method. The activation is noted using solubilsation of dyed substrates (a), reduction of viscosity (b) but not when the cleavage events are measured directly (c).

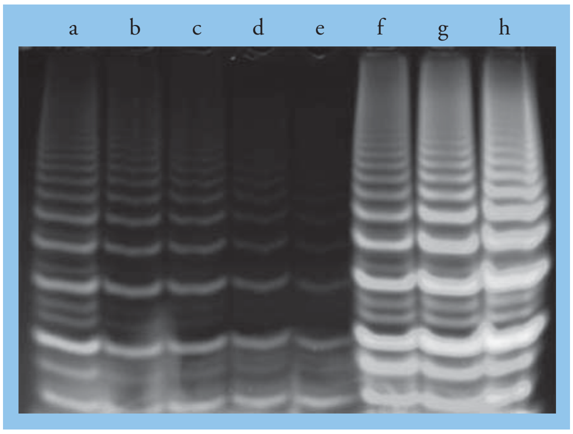


Figure 3 Fluorescent maltotriose is incorporated into higher molecular weight products by limit dextrinase. The figure shows the effect of increasing maltotriose concentration on transfer of fluorescent maltotriose into higher Mr products (lanes a-e). Lane a - no maltotriose; lane b - 2.5 mM; lane c - 5 mM; lane d - 12.5 mM; lane e - 25 mM. Lanes f-h show the effect of increasing enzyme content on transglycosylation.

Other experiments suggested that the degradation of substrates by LD in the presence of maltodextrins did not generate as many low molecular mass products as expected. Therefore, the activation of LD involved altering the pattern, rather than the rate of enzyme action.

To examine this phenomenon more closely the fate of the maltodextrins was monitored during the activation reaction. By synthesising a fluorescent derivative of maltotriose, the process could be traced using a novel form of electrophoresis, fluorophore-assisted carbohydrate electrophoresis (FACE) (Fig. 3). The fluorescent maltotriose was incorporated into higher molecular mass degradation products during the activation reaction (Fig. 3), but this was inhibited by the addition of unlabelled maltotriose. The extent of incorporation of fluorescence was directly linked to the purity and activity of LD.

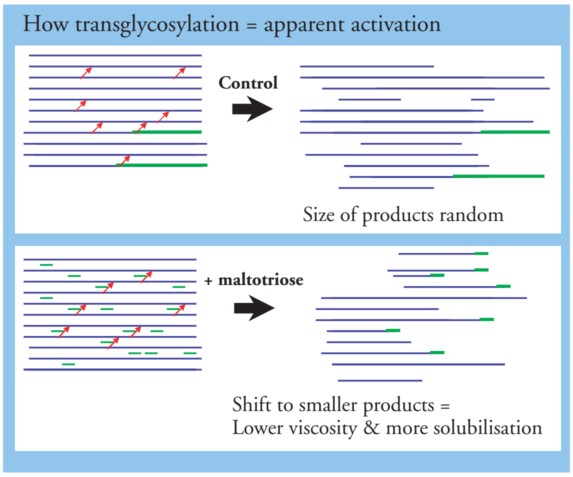


Figure 4 Scheme for transglycosylation reaction. In a proportion of cleavage events, LD transfers the cut end of one amylopectin chain to another glucan forming a new α-(1-6) linkage instead of transferring it to water and effecting hydrolysis.

The simplest explanation for these observations is that LD does more than simply cleave branch points. It can transfer the cut ends of the amylopectin molecule to maltodextrins, i.e. it can catalyse transglycosylation as well as transferring the cut ends of amylopectin to water hydrolysis (Fig. 4). Although structurally related enzymes that synthesise or degrade starch can catalyse transglycosylation reactions, this form of activity has never been recorded for LD. The ability of LD to transglycosylate may cause the reformation of certain, particularly resilient, branched dextrins during starch degradation in malting barley. In addition, the transglycosylation may be useful to modify industrial-scale saccharification to glucose- or maltose-rich syrups.

References

[1] MacGregor, A.W. (1996). *Journal of the Institute of Brewing* **102**, 97-102.

[2] Ross, H.A., Sungurtas, J., Ducreux, L., Swanston, J.S., Davies, H.V. & McDougall, G.J. (2003). *Journal of Cereal Science* **38**, 325-334.

Lessons from barley recommended lists

M. Macaulay, J. Russell, L. Ramsay, D.F. Marshall, W. Powell, R. Waugh, & W.T.B. Thomas

The UK barley market requires high-yielding cultivars with good agronomic characteristics and, especially for spring barley, good malting quality. Barley breeding in the UK is very competitive with over 35 spring and winter barley entries, derived from many European as well as UK breeding programmes, submitted to National List Trials yearly. Since 1993, 125 spring and winter barleys have been evaluated in the HGCA/CEL funded Recommended List Trial (RLT) system for the UK leading to 64 new recommendations. As new recommendations have to show improvement in at least one character over existing cultivars, the average of over 6 new recommendations each year demonstrates that real breeding progress is being made. The pedigrees of recommended cultivars clearly demonstrate that commercial breeders are achieving this progress largely by working with crosses between elite genotypes. Moreover, Marker Assisted Selection (MAS) has, to date, not been widely deployed by commercial breeders. We have used the RLT yield and Hot Water Extract (HWE) data collected over the period 1993 to 2003 to highlight the advances that are being made through conventional phenotypic selection as this sets the standard that MAS must be judged against. We have combined the HWE phenotypic data with genotypic and pedigree data to trace the advance in winter malting quality since the introduction of Maris Otter and thereby illustrate a potential means of deploying MAS for HWE in winter barley.

Since 1992, 72 spring and 82 winter barley genotypes have been grown in fungicide-treated RLTs at sites throughout England, Scotland and Northern Ireland, resulting in yield (t ha^{-1}) data from a total of 228 spring and 237 winter trials. A more restricted set of malting quality data was available for 50 spring and 50 winter cultivars from five selected sites each year from 1995 to 2002 inclusive. From each site, the mean grain nitrogen (GN) content and hot water extract (HWE) were used to derive a hot water extract corrected to 1.5% grain nitrogen content (HWEc) using the formula HWEc=HWE+11(GN-1.5) following Bishop[1] as this gives a more accurate representation of varietal performance over contrasting seasons. These data were used to estimate overall mean plot yields (PY) and HWEc for each entry. For both spring and winter barley, the PYs of the highest yielding cultivars on the 2003 recommended list (Doyen and Colossus respectively) were over 0.6t ha^{-1} greater than those of the highest yielding cultivars on the 1993 list (Fig. 1). Improvements in HWEc of at least 3 Linter° kg^{-1} were also apparent in comparisons of the cultivars on the 2003 and 1993 recommended lists. We tested the significance of the breeding progress by regressing the means of each cultivar placed on the recommended list from 1993 onwards against the year that it was first recommended. This showed that the genetic improvement in PY was 0.8 and 0.9% *per annum*, accounting for 58 and 34% of the variation amongst the cultivar means for spring and winter barley respectively (Fig. 1). Whilst malting data was available for a wider range of RLT entries, we restricted our analysis of breeding progress to those that had at least been provisionally recommended by the Institute of Brewing for use by UK maltsters. Despite this restriction, we found evidence of significant genetic improvement in HWEc for spring barley that accounted for 43% of the phenotypic variation in the character. We did not, however, find any significant genetic improvement in HWEc for winter barley, largely because newly recommended cultivars do not

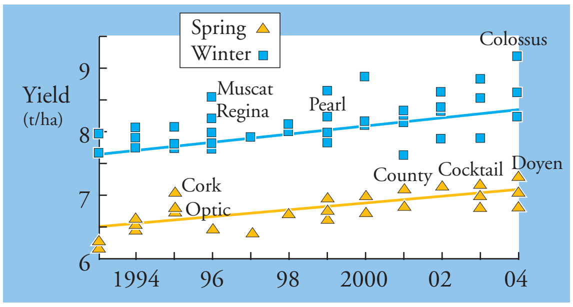


Figure 1 Recommended list treated yield against year of first recommendation.

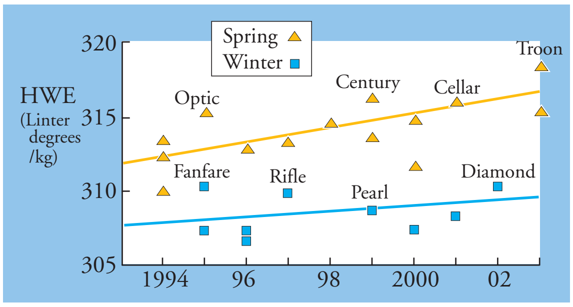


Figure 2 Recommended list hot water extract corrected to 1.5% grain nitrogen against year of first recommendation.

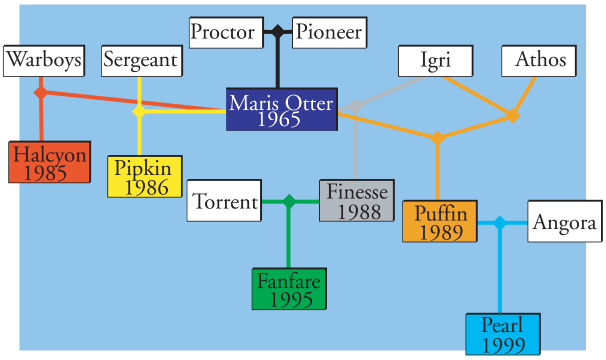


Figure 3 Pedigree tree of UK bred recommended winter barley malting cultivars and year of first recommendation.

	SSR1	SSR2	SSR3	SSR4	SSR5	SSR6	SSR7	Predicted HWE
M Otter	1.1	1.5	0.7	0.2	0.7	1.4	-0.3	309.0
Halcyon	1.1	1.5	0.7	0.1	0.4	0.4	0.4	309.1
Pipkin	1.1	0.2	0.7	1.3	0.7	0.2	-0.3	307.5
Puffin	1.1	0.2	0.7	1.3	0.7	1.4	0.5	308.2
Fanfare	1.1	1.5	0.7	0.2	0.4	1.4	1.1	309.8
Pearl	1.1	1.5	0.7	1.3	0.7	1.4	-0.3	309.8
Angora	1.0	1.5	0.7	1.5	0.7	0.2	1.1	310.2
Regina	1.0	0.2	0.7	1.3	0.7	1.3	0.4	309.1
Optimal	1.1	1.5	1.3	1.5	0.7	1.4	1.1	312.1
Igri	-1.5	0.2	0.7	0.6	-0.8	0.6	-0.7	302.5
Torrent	-1.5	0.2	-1.3	-2.3	0.4	0.0	0.4	299.4

Figure 4 Graphical representation of allelic diversity of UK winter barley malting cultivars and some parents at seven loci significantly associated with hot water extract and estimates of allelic effects.

exceed Fanfare, which was first recommended in 1995 (Fig. 2).

We have genotyped most of the RLT entries using 48 previously mapped SSR markers and the fragment sizes associated with each allele converted into frequencies and coded accordingly. We combined these genotypic data with the overall mean HWEc from our analysis of the winter barley data and used analysis of variance to test for differences in the SSR allele group means for winter barley HWEc at each locus. This detected significant associations of 10 SSR loci with HWEc but, as the map locations of the SSR loci were known, we discarded three because neighbouring loci had similar but more significant effects.

Pedigree analysis of the UK-bred winter cultivars reveals that they are all derived from Maris Otter which was introduced in 1965 (Fig. 3) and they exhibit considerable similarity in their alleles at the seven SSR loci associated with HWEc (Fig. 4). For instance, they all have the same alleles at SSR1 and SSR3, both of which appear to have been transmitted from Maris Otter. Furthermore, the Maris Otter allele is found in three of the UK cultivars for SSR2 and SSR6. By contrast, two other ancestors in the pedigrees of the UK cultivars share few alleles at these loci and also possess at least one allele with a marked detrimental effect upon HWEc. Whilst Angora and Regina have also been placed on the UK recommended list, they were both derived from the Breun breeding programme in Germany and their pedigrees cannot be traced in such detail as they contain breeders' codes. Whilst Angora and Regina have a different allele at SSR1 from the UK-bred cultivars, at least one of them shares an allele at the other six SSR loci. These data suggest that several of the seven SSR loci associated with HWEc could be used in MAS for assembling an elite malting quality gene pool and then using phenotypic selection to pick out the best. Intriguingly, none of the cultivars possesses the best allele at all seven loci. Assuming that effects are estimated accurately and the loci act in an additive manner, assembling optimal alleles at all seven loci would increase HWEc by nearly 2 Lintner° kg^{-1}.

We thank Crop Evaluation Limited for use of data collected on the HGCA-funded UK spring and winter barley RLTs.

References
[1]Bishop,L.R. (1948) *Journal of the Institute of Brewing*, **54**: 330-333

The transcriptional complexity of barley development

A. Druka, I. Druka, D.F. Marshall, J. McNicol & R. Waugh*

Since the late 1990s, the establishment of microarray technology has allowed the abundance of messenger RNAs (mRNAs: the intermediates between genes and proteins) derived from thousands of genes to be measured in a single experiment. The ability to monitor how the majority of the mRNA transcripts in a cell or tissue change in abundance over time, in different tissues or in response to environmental cues is immensely powerful and helps identify networks of genes that are co-regulated or that are specific to individual tissues or cell types, even if the functions of the genes are not currently known. Microarray data is thus informationally very rich, and using relatively simple designs such experiments have yielded the first insights into the gene expression networks that control a range of biological processes.

Over the last three years we have collaborated with the world barley genomics community and a commercial vendor to develop the technically robust Barley1 microarray that exploits GeneChip® technology. It can be used to assess the abundance of mRNA transcripts from over 20,000 different barley genes at one time. We have used this system to examine mRNA abundance in a range of different barley tissues representing the major stages in the development of the barley plant. The tissues are shown in Fig. 1A. This developmental experiment has provided insight into how mRNA transcript population complexity changes in different tissues during development and will act as a reference for future studies in barley and other grass species including wheat, rice and maize.

We investigated mRNA transcript population complexity by measuring for each tissue the number of genes that were expressed, the level at which they were expressed and how that level changed between the tissues examined. Looking at the complete mRNA population as a whole (termed the 'transcriptome') we found that highly differentiated tissues such as anthers

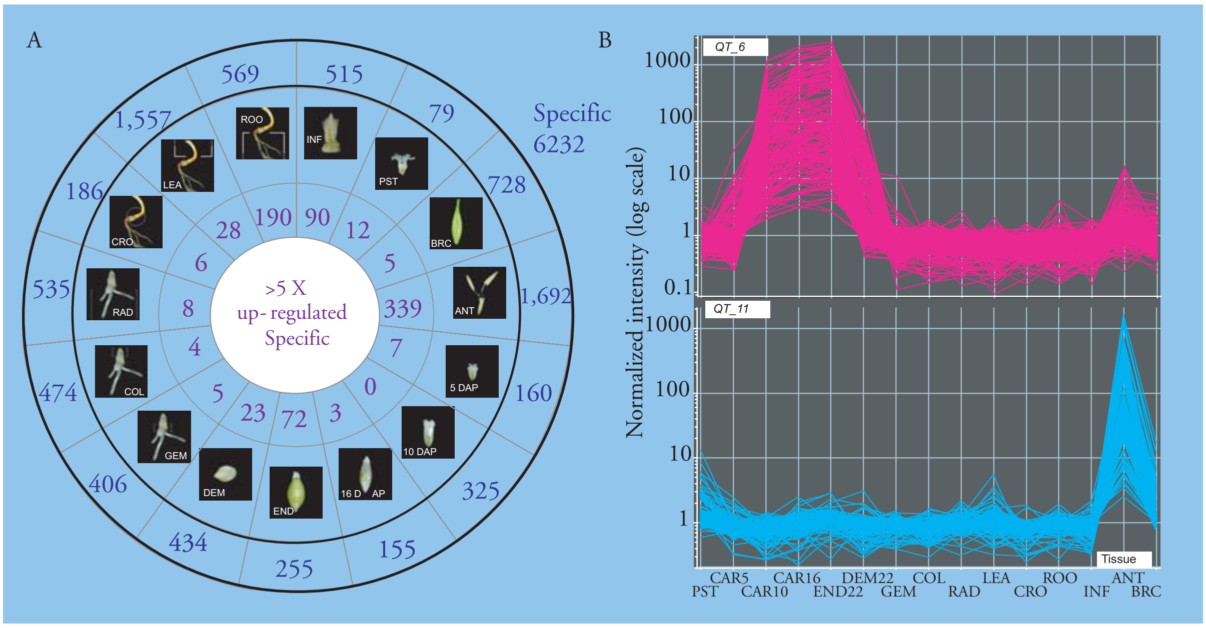


Figure 1 (A) Tissues we used to investigate transcriptional complexity of barley development. Respective Cereal Plant Anatomy and Plant Growth stage terms were according to ontologies developed by Gramene. The following are the tissue abbreviations: INF, inflorescence; PST, pistil; BRC, bracts (lemma, palea and glumes); ANT, anthers; CAR5, caryopsis 5; CAR10, CAR16; END22, caryopsis without embryo; DEM22, embryo; GEM, mesocotyl; COL, coleoptile; RAD, seminal root; CRO, crown; LEA, leaf (partially shown); ROO, root (partially shown).
(B) Two examples of clusters of genes that show similar patterns of gene expression across all 15 tissues examined. The top panel shows genes that are predominantly expressed during stages of seed development. The bottom panel identifies genes that are specifically expressed only in the developing anther tissues. In both cases a large number of 'unknown' genes cluster together with those of established function.

*This report is the summary of an international collaborative project:.
Druka,A., Muehlbauer,G., Druka,I., Caldo,R., Baumann,U., Rostoks,N, Schreiber,A, Wise,R., Close,T, Kleinhofs,A, Graner,A, Schulman,A., Langridge,P, Sato,K, Hayes,P, McNicol,J, Marshall,D & Waugh,R. (2004) submitted

expressed fewer genes than tissues containing many or actively proliferating cell types with a high positive correlation (r=0.94) between the number of genes expressed in a tissue and the total amount of mRNA (as a fraction of the total RNA which includes the ribosomal RNA). These observations allowed us to conclude that the amount of mRNA in a tissue is largely determined by the number of unique transcripts in the population, rather than varying the abundance of an existing set.

By comparing the lists of genes that were either on or off in the different tissues, the experiment showed that a large number of genes are turned on or switched off during barley development. To look at underlying trends in the dataset we then applied two complementary statistical analyses. The first allowed us to identify genes that are specifically switched-on in individual tissues and the second to group genes that showed common patterns of gene expression across all fifteen tissues. Fig. 1A gives the result of the first analysis. The numbers associated with each of the tissues represent the number of genes that we detected that were specifically expressed, and the subset of these that were >5-fold more abundant, in the indicated tissue compared to any other. These numbers therefore reflect the uniqueness of the individual transcriptomes. Barley anthers for example possess the greatest number of 'specific' transcripts compared to any of the other tissues and the caryopsis at 16 days post anthesis the least. The genes encoding these specific transcripts represent a valuable collection of candidates that can be used to investigate in great detail the underlying biology of the sampled tissues.

Fig. 1B gives two examples of the second type of analysis and shows how genes can be 'clustered' together based on common patterns of abundance across the tissues. Examining the information associated with the genes included in these groups revealed that where specific functions were known, the different members of the co-regulated clusters were frequently functionally related. However it also showed that a considerable portion of the co-regulated clusters were made up of unknown or hypothetical proteins. As a result of this analysis we can putatively assign functional annotations to each of these genes based solely on mRNA transcript abundance-based functional correlations.

Further detailed analysis of this developmental mRNA transcript abundance dataset confirms that it contains information that reflects known biological patterns and that it has considerable descriptive and predictive biological potential. Free public access will soon be available and we predict that this dataset will act as both a reference and a catalyst for hypothesis driven research in barley and other grasses by providing robust and representative transcript abundance profiles of approximately 22,000 genes.

Origins of genomes in polyploid potato species

G.J. Bryan & G. Ramsay

Why have some wild potatoes become polyploid? Whole groups of species (in series *Longipedicellata, Demissa, Acaulia* for example) have four or six sets of chromosomes, compared to two in normal diploids, and indeed most of our cultivated potatoes are also polyploid. Wild potato polyploids which are hybrid in origin (allopolyploids) have profoundly changed their strategy for persisting and evolving in their environment. They are largely isolated from their diploid progenitors and so cannot readily exchange genes with them. Along with the fixed heterozygosity comes a degree of hybrid vigour and metabolic diversity, but also a shift from outbreeding, characteristic of most diploid species, to the ability to self-pollinate. This loss of self-incompatibility probably arises from the inability of SI systems to work properly in polyploids, and fundamentally alters the genetics of populations of the species. The shift to self-fertility has advantages where individuals are widely-scattered, or where insect pollinators are infrequent or unreliable. In fact, competition in high altitude *Solanum* and other alpine plants for the few, generally large insect pollinators found at these altitudes appears to lead to either large, showy flowers or a switch to smaller, less conspicuous self-pollinating flowers. One additional effect of the change towards homozygosity is the increased ability to exploit recessive alleles whose effects could be lost in interbreeding and genetically diverse populations. It is possible that this change in breeding strategy can permit different approaches to survival when wild populations are under threat from virulent pathogens.

Why does the origin of the genomes in these polyploid wild species matter? These polyploids are often sources of valuable genes for potato breeding. *Solanum demissum*, for example, has been the main source of many key blight resistance genes. Are there better sources of these genes in the diploid species which gave rise to hexaploid *S. demissum*, and indeed do they still survive? In some cases, polyploid species may be acting as reservoirs of the genomes of extinct diploid ancestors, raising the intriguing possibility that if it was possible to cause polyploids to lose one or more genomes, extinct precursor species may be regenerated. Such flights of fancy may be unrealistic, but it is the case that both polyploid and diploid wild species from the Commonwealth Potato Collection (CPC) are increasingly important for the development of new cultivated potatoes with enhanced ability to fight pests and diseases. For exploitation strategies to proceed efficiently, it is important to understand the origins and relationships of the available genomes.

Use of molecular marker and DNA sequence data offers an approach for studying genome origins and relationships in tuber-bearing *Solanum*. We have used the highly multiplex Amplified Fragment Length Polymorphism (AFLP) method to 'fingerprint' CPC material, comprising representatives of the major diploid series and all of the main polyploid groups. These data suggest strong taxonomic affinities between species of differing ploidy, suggesting that they share genomes ultimately derived from diploid progenitors. For example, members of the hexaploid series *Demissa* and the largely tetraploid *Acaulia* cluster together. It appears that the two groups have two genomes in common, with series *Demissa* possessing an additional genome from a further hybridisation event. This is particularly interesting as these two polyploid series have very distinct geographic origins with *Acaulia* only being found in S. America and series *Demissa* being of Mexican origin. It has been suggested that the Mexican diploid and, almost uniquely, self-fertile species *S. verrucosum* provided the additional genome found in *S. demissum.* Our evidence appears to confirm this, and indicates that perhaps the allotetraploid stock similar to *S. acaule* was only able to survive the high selection pressure presented by late blight populations in Mexico by forming secondary hybrids with *S. verrucosum*, a species well-adapted to the pathogen. We also see an association of these species with members of the tetraploid Mexican series *Longipedicellata*, suggesting that these series share genomes of common origin. However, AFLP marker-based profiles are not ideally suited to this purpose, lacking the resolution required to identify individual genomes. A more appropriate strategy is the use of PCR to amplify single-copy gene segments from the different genomes contained in diploid and polyploid taxa. PCR primers were designed to conserved regions of genes such that the derived products span more rapidly-evolving intronic regions. DNA sequence was obtained for three nuclear and four chloroplast gene fragments from ~25 species representing the majority of diploid and polyploid groups of *Solanum*. Rates of chloroplast gene sequence polymorphism are extremely low (~1% nucleotide polymorphism). Nonetheless phylogenetic analysis of our data suggests close relationships between polyploid series *Acaulia*, *Longipedicellata*, and *Demissa* and with Mexican diploid *S. verrucosum*, strengthening the hypothesis that these groups share common origins and suggesting that the Mexican diploid may be the maternal parent of these polyploids. The nuclear gene data are more variable (11-28% nucleotides polymorphic). Analysis of a ~450bp fragment of a sucrose synthase gene reveals intriguing relationships between the sequences from polyploid series *Acaulia*, *Longipedicellata*, and *Demissa* with those from diploid series *Tuberosa*, *Piurana*, *Pinnatisecta* and *Megistacroloba* (see Fig. 1). It is likely that series *Longipedicellata* may have evolved from series *Pinnatisecta* and *S. verrucosum* and series *Acaulia* from *Piurana* and an unknown diploid. The hexaploids appear to be derived from *Acaulia* plus the genome of *S. verrucosum*. With a clearer view of the origins of the genomes in these polyploids, we are now in a better position to decide where, for example, novel resistance genes are likely to be found.

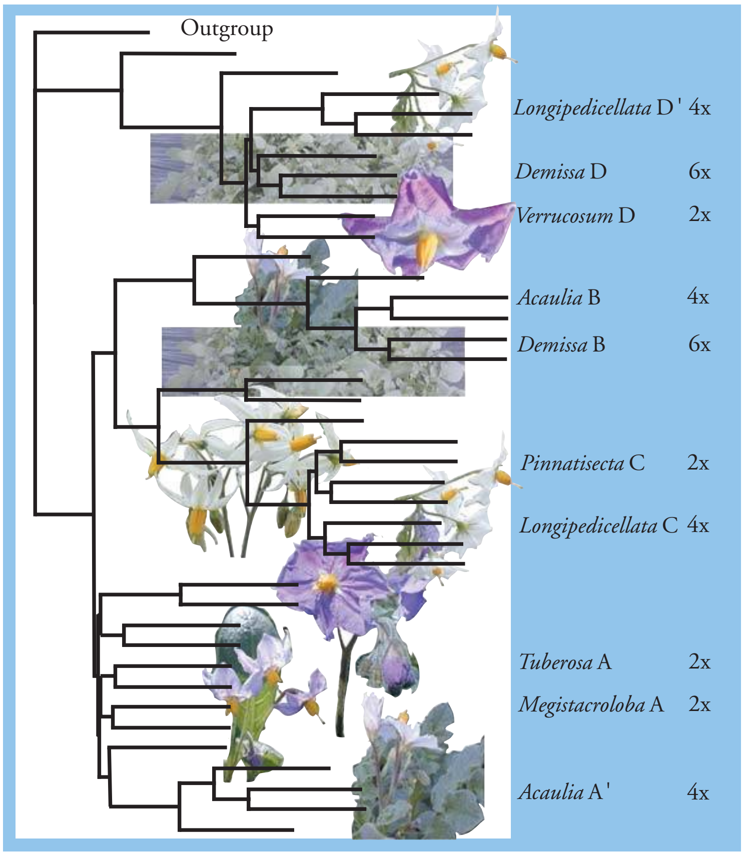
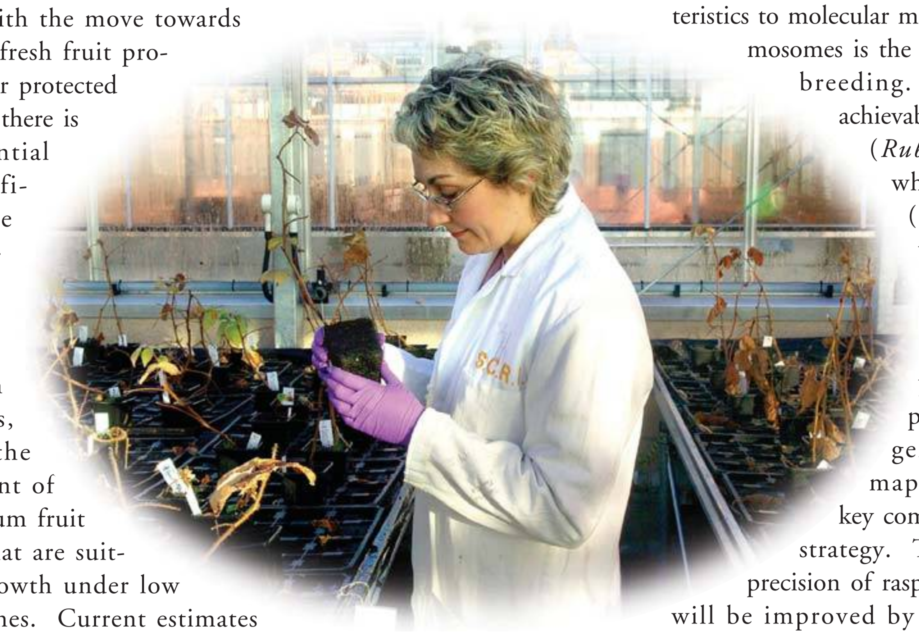


Figure 1 Relationships between the genomes in polyploid groups and their diploid ancestors in wild potatoes, determined from the DNA sequence of sucrose synthase gene fragments.

Raspberry mapping and marker-assisted breeding

J. Graham, K. Smith & I. Tierney

The raspberry industry in the UK is currently worth £52 million, making it the third most valuable fruit crop after strawberries and dessert apples. With the move towards high-value fresh fruit produced under protected cultivation, there is great potential for a significant increase in production and, therefore, consumption of fresh raspberries, through the development of new premium fruit cultivars that are suitable for growth under low input regimes. Current estimates suggest only 6% of the UK population consume fresh raspberries each season. For future expansion, new cultivars producing high quality fruit over a longer growing season and with genetically based durable pest and disease resistance must be developed. Breeding in raspberry, however, is time-consuming due to its highly heterozygous nature and relatively long period of juvenility.



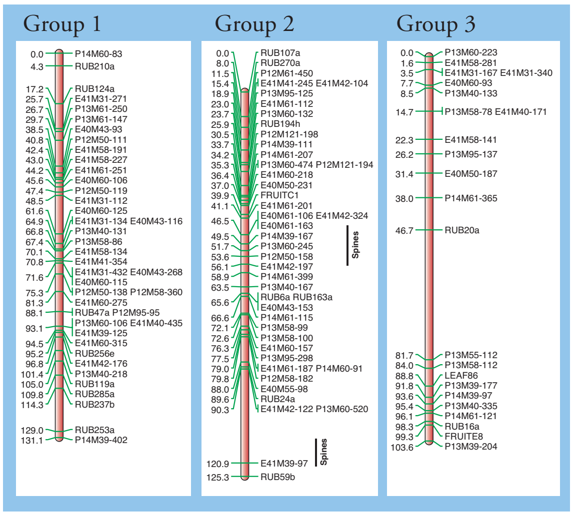


Figure 1 Raspberry genetic linkage groups 1-3.

Understanding the genetic control of commercially and nutritionally important traits such as fruit quality and disease resistance and the linkage of these characteristics to molecular markers on chromosomes is the future of plant breeding. This is now achievable in raspberry (*Rubus idaeus*), which is diploid (2n=2x=14) with a small genome (270 Mb). Over the last three years, we have produced a genetic linkage map which is the key component of this strategy. The speed and precision of raspberry breeding will be improved by utilising this genetic linkage map[1], to develop diagnostic markers for polygenic traits and the identification of genes controlling complex phenotypes. The raspberry genetic linkage map has been constructed from a full-sib family generated from a cross between two phenotypically different cultivars: the recent European cultivar, Glen Moy, released from SCRI in the 1980s and the older North American cultivar, Latham, estimated to be around 60% similar at the genetic level. Latham was one of the first cultivars produced through controlled breeding in the 1930s, and is an exceedingly hardy, extremely spiny, brown-caned, small, round, glossy-fruited plant with very sweet aromatic darkish fruit and, importantly, with resistance to raspberry root rot, yellow rust and cane spot. Glen Moy, released in 1981, in contrast, is a large conical-fruited cultivar with good, slightly sweet flavour, good sensory characteristics, susceptible to low temperature damage, spine-free and green-caned with other disease resistance including cane botrytis and spur blight. The map of the seven raspberry chromosomes, and incorporation of ever greater numbers of co-dominant molecular markers that enhance resolution, can be translatable into targeted breeding for traits that meet grower, retailer and ultimately consumer requirements.

Understanding and then utilising the genetic basis of important traits including sensory quality and pest and disease resistance is a major challenge in a rapidly evolving market. With the increasing demand for high-quality fruit grown in low input/Integrated Crop Management (ICM) production systems, rather than the repeated pesticide/fungicide regimes that have been the norm for most producers, the main obstacle is a lack of cultivars resistant to some of the most damaging pests and pathogens, notably to raspberry root rot caused by *Phytophthora fragariae* var. *rubi*. In this case, no commercially viable resistant cultivars are available.

With the development of the raspberry genetic linkage map, the next stage is to define and delineate genetic traits relevant to pest and disease resistance, berry and fruiting quality and commercially acceptable plant architecture by the identification of trait-linked DNA markers. This will give breeders a tool kit for marker-assisted breeding technologies leading to the more rapid production of premium quality varieties with resistance to raspberry root rot and other pests and diseases of importance, thus enhancing the success of new varieties. For example, raspberry root rot has a devastating effect on many growers, rendering their plantations uneconomic and ultimately unsuitable for raspberry production. The control measures for root rot involve the use of significant quantities of fungicide coupled with modified growing regimes. However, by mapping the genetic basis of resistance in the Latham Glen Moy cross, an understanding of the genetics of the resistance in Latham coupled with the development of diagnostic markers linked to disease resistance can be incorporated into future breeding programmes. The use of markers to detect disease resistance will greatly reduce the breeding time of new cultivars by eliminating the need for 3-4 years of glasshouse and field screening currently required per cross to identify resistant progeny. The linkage map developed here will provide an excellent genetic framework for qualitative and quantitative trait analysis for the Rosaceae. A major future thrust will be to move from anonymous markers to functional polymorphisms based on expressed sequence tagged simple sequence repeats (EST-SSRs) and single nucleotide polymorphisms (SNPs). Access to mapped markers will allow new approaches to breeding of complex traits that are difficult to manipulate in breeding programmes.

References

[1]Graham, J., Smith, K., MacKenzie, K., Jorgenson, L., Hackett, C. & Powell, W. (2004) *Theoretical and Applied Genetics* **109**, 740-749

Management of genes and organisms in the environment

G.R. Squire

The argument held sway that arable ecosystems are too complex to manage for a range of ends – for high production, biodiversity and low pollution. However, major findings from recent large-scale experiments, notably the first results of the UK's GM field experiments, demonstrated that small shifts in crop variety or agronomy could lead to consistent change in plant and animal populations over the whole arable land surface. The finding that a small effect can emerge above the 'noise' of weather and locality, means that manipulations through new varieties or new agronomy, patch by patch, field by field, could accumulate to have global impact for the betterment of the ecosystem. To achieve such effects economically requires detailed knowledge of arable systems and landscapes, and in particular their properties of resistance and resilience, which have been major topics of research in the Theme.

Resistance and resilience The resistance of a system helps it to repel or reduce the initial effect of a force on it, while resilience allows the system to recover if the force deflects it (e.g. fire, ploughing, grazing, a nuclear winter, bioterrorism, etc.). Resistance and resilience are always, to an extent, in opposition. Things that tend to be resistant to forces are rarely highly resilient, and vice versa. Take the arable field, for example - it is not highly resistant, it is always being severely affected by forces such as ploughing, spraying and planting crops; but it has great resilience, mainly through the buried propagules and sown seed which each year regenerate the food web without which the system would collapse. Science can, we believe, guide stewardship to implement the specific mix of resistance and resilience that would keep the arable system sustainable over a long period. We can influence the balance between resistance and resilience by encouraging the right organisms and by manipulating their configuration in space and time by, for example, crop mixtures, refuges and tillage (see following article by Newton *et al.*). There is no single solution, rather a range of options which together would bring diversity in the primary producers and the skeletons and chemicals they generate and leave behind. The plant assemblages of the arable field, including the crop, can be more complex than generally supposed, interacting to produce structures based on the varying architectural properties of the species. Methods to quantify and model such architecture are recent additions to the suite of techniques employed to study seedbank-based food webs (see following article by Karley *et al.*). Yet while scientific study is showing how the seedbank can be managed as a source of variety in the food web, the astonishing complexity of soil provides problems of a higher order.

Managing resilience in the soil system How readily are soil organisms and soil processes manipulable through the plants that grow on them, in the case of arable soils, the crops and weeds? Research in recent years on ubiquitous processes such as nitrification by soil bacteria shows that the rates of processes differ greatly between fields and during the season in the same field, to such an extent that the field appears to have a life of its own, almost independent of the vegetation grown on it in any year and even of the total bacterial population. The connexion between the plants and the soil microorganisms is complicated, yet progress on this seemingly intractable problem is being made at both fundamental and practical levels. One of the main, potential mechanisms by which roots influence soil organisms is through the border cells that are continuously sloughed off root caps (see following article by Bengough *et al.*). If the nature and content of these cells differs systematically between plant-types, it would be feasible to breed new crop varieties, or manage weed communities, so as to influence soil organisms in a way that increases structural integrity and resilience.

The topical issue of the biosafety of insect-resistant crops is a further case in point. The particular question is whether GM maize expressing the *Bacillus thuringiensis* toxin (Bt) has any effect on non-target organisms and the soil processes which they mediate. If Bt maize were to have adverse effects on these organisms, and thereby reduce the resilience of the soil, it might counter some of the pesticide-reducing benefits of the crop. Experiments needed to answer the question are straightforward in design but they require detailed, existing knowledge of soil organisms, their interactions and their role in soil processes (see following article by Griffiths *et al.*). Without such knowledge, the questions are simply not answerable, and SCRI brings the appropriate expertise to the multi-partner project (ECOGEN) that is tackling the problem.

Dispersal and epidemiology Resistance and resilience are also properties of arable landscapes, which are affected both by cumulative small shifts in the component fields, but more so by their connectivity and by their contact with other ecosystems and countries. The 'porosity' of a region to insect pollinators or pests and its openness to invasion by organisms are properties above those of the individual fields and field margins. An understanding of what determines connectivity and porosity is essential for pre-empting or managing epidemics and for ensuring that different crop-types are able to coexist. We report here two examples, one each from our two main lines of enquiry at this scale, epidemiology and crop purity. The first (see following article by Fenton *et al.*) examines the spread and dynamics of aphid biotypes using a range of expertise including molecular population biology. The second is the detection and persistence of GM herbicide tolerant oilseed rape, arising as an imported impurity or residual from field experiments (see following article by Squire *et al.*). Another major project led by members of the Theme is the study of European populations of the potato late blight pathogen (*Phytophthora infestans*). There is no question that managing crops, pests and impurities at the landscape scale will become a feature of European agriculture in the years ahead. SCRI is well on the way to developing the appropriate concepts and tools.

Making a difference - putting science into practice In summary, our scientists have made a difference this year to the way production systems are understood and managed. We have helped improve yield and sustainability in developing countries; advised on biosafety and biovigilance in Europe, the tropics and North America; influenced GM policy in several EC member states and continued to play a coordinating role in international, multi-partner projects. Nearer home, we have strengthened our gene-to-landscape philosophy through formal, collaborative relations with the trials and advisory group, Scottish Agronomy. And in partnership with the Estate, Glasshouse and Field Research Unit at SCRI, we have been very active in the LEAF organisation (Linking Environment and Farming): consolidating SCRI as a LEAF Innovation Centre (see preceding article Birch *et al.*), explaining science through public meetings and developing an experimental infrastructure to examine major issues in arable land usage. There are many opportunities to exploit biodiversity and enhance crop resilience in new cropping systems, for example using industrial crops or skillfully exploiting heterogeneity in arable vegetation. Working with organisations like LEAF and Scottish Agronomy enables us to get first-hand experience of problems whose solutions will improve the economy of agriculture and the betterment of the environment. It needs to be stressed, again, that none of the practical successes would have been possible without the base of fundamental science - our detailed knowledge of soils, plants, microbes, genes and habitats, our use of the latest methods in bioinformatics and modelling and SCRI's wider excellence in genetics and microbiology.

Crop diversity - new opportunities for low-input industrial crops?

A.C. Newton & J.S. Swanston

Modern cereal varieties have generally been bred for agricultural systems, where short-term optimisation of the environment for plant growth is achieved by high inputs and soil loosening with intensive tillage. Many traits have thus been selected against and lost from the elite germplasm today's breeders utilise. For example, modern varieties use fertiliser nitrogen very efficiently but may have reduced ability to access soil nitrogen compared with old varieties. Similarly, disease escape characteristics such as leaf habit and straw length are important where inoculum is present, but waste resources that could be put into grain fill where fungicides are used. However, any loss in grain yield may be compensated for through reduced fungicide use, and increased exploitation of the total biomass.

Agriculture has become dependent on non-renewable sources of fuel and agro-chemicals. Recognition of this has encouraged development of lower-input cultivation and also the use of crop plants as sources of fuels and chemical feedstocks. Increasingly, too, uses are being sought for crop residues such as straw. One example of industrial use is bioethanol (alcohol) derived from cereal grains or sugar cane and used as a partial petrol replacement. At present, despite considerable lobbying from farmers' groups, there is no production in the UK, although there is considerable expertise in distilling alcohol from cereals, particularly in Scotland. Work done in several areas at SCRI can greatly assist in producing optimal raw materials, particularly wheat, for distilling.

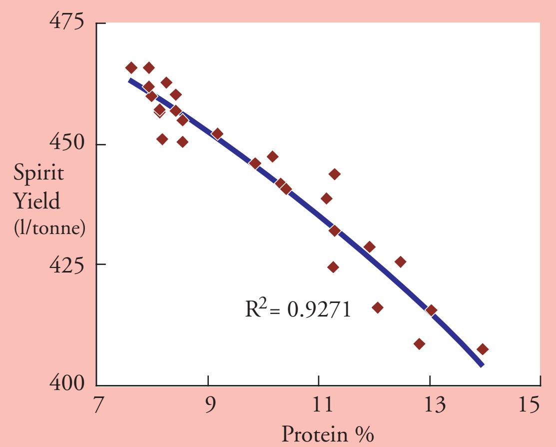


Figure 1 Spirit yield (litres/tonne) plotted against protein content for 9 samples from each of 3 varieties of wheat.

Collaborative work with the Scotch Whisky Research Institute has shown the strong negative correlation between spirit (alcohol) yield and grain protein content (Fig.1).

As a 1% increase in protein reduces spirit yield by approximately 9 litres per tonne, distilling wheats should be cultivated under conditions leading to low N levels, but this may have a deleterious effect on yield. In addition, the best yielding cultivars such as Deben give less alcohol than varieties like Riband and Consort but have better disease resistance to, for example, *Septoria tritici*. While this presents a target for plant breeding, varietal mixtures may offer a short-term solution. Data from an SCRI trial (Fig. 2) shows that a mixture containing Deben gave spirit yields comparable to those of the other components. Grain yield of the mixture was very similar to that of Deben, and in a bad disease year Deben would contribute to lower disease whilst the mixture would compensate for its poor lodging characteristics.

Growing crops as heterogeneous mixtures of species, varieties or near-isogenic lines, not only enables contrasting traits present in different varieties to be grown as a crop together, but also allows exploitation of spa-

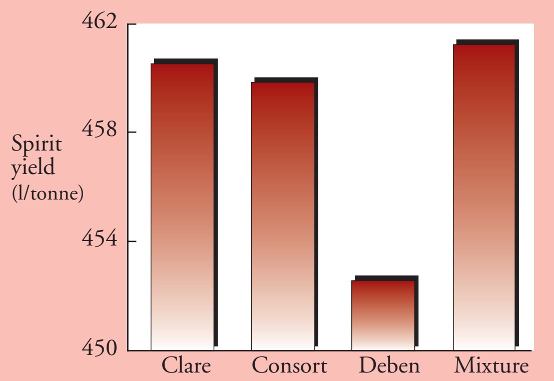


Figure 2 Spirit yields of 3 cultivars and an equal proportion mixture of the 3, from SCRI trial.

Figure 3 Barley field trials of mixtures at SCRI.

tial and temporal complementarity and synergy. In the lifetime of an arable crop it is exposed to many different environments both spatially in different parts of a field and in different parts of the crop canopy, and temporally throughout the season. To expect a single genotype to be able to respond optimally to all these stresses be they biotic (e.g. fungal pathogens) or abiotic (e.g. frost, low nutrients, high humidity etc), may be unreasonable. Mixing different genotypes together can considerably enhance the options a crop phenotype has from which it can respond, making it a much more resilient production system. Whilst we are seeking to understand these characters in single genotypes, their range of expressions can be immediately extended by simply accessing more and diverse genotypes and deploying them together.

Complex cereal cultivar mixtures reduce disease compared with the mean of their component monocultures thereby reducing pesticide inputs. They also yield more, for example up to 15% in winter barley thereby utilising nutrients better, or allowing reduced fertiliser inputs for the same yield. Such results can be achieved with current cultivars, thus only utilising a very restricted and highly selected portion of the potential variability and synergies potentially exploitable. Strategies for combining modified crop agronomy (lower inputs) with appropriate germplasm should also include accessing landrace and old varieties for deployment in genotype mixtures, where synergies and compensation between intelligently designed component combinations can be exploited for maximising resource exploitation. Attributes now deficient in modern varieties include increased straw biomass. Straw is currently used for energy (heat and electricity) production in Denmark, but may also be a source of fermentable sugars, if problems relating to initial breakdown of the cellulose fraction and fermentation of the 5-carbon sugars, deriving from hemicellulose can be overcome.

Other desirable attributes to re-introduce include some disease resistances, ability to utilise soil nitrogen, allelopathy, and interaction with micro-organisms such as mycorrhiza. Mixtures are likely to have greater climatic extreme resilience such as drought or cold tolerance. However, they are equally effective for obtaining greater productivity from high yield potential, benign environments, particularly utilising modern varieties bred for such conditions. There is nevertheless the potential to design the heterogeneity to minimise compromises and maximise synergies given knowledge of the nature and probability of the stress factors. Variation range not utilised may be costly to yield or quality, so design parameters should have tolerances appropriate for given production systems to be balanced and thereby resilient, i.e. having greater buffering capacity for both biotic and abiotic stresses, within reasonable risk ranges.

It is assumed that mixtures must be homogeneous for all the components, but this does not take into account the effect of Genotype Unit Area. For control of pathogens discontinuity of susceptible host genotype is a component of epidemic control, maximising barrier effects. Whilst the proportion of susceptible hosts may remain constant, spatial distribution of the resistant host affects its efficacy. It is difficult to control spatial geometry of plants with normal farm drills for cereals, but the degree of patchiness may affect mixtures efficacy and for different diseases in different ways depending partially on spore dispersal gradients. Furthermore, these spatial interactions with epidemiological factors may be different again from both above and below ground resource exploitation interactions.

Figure 4 Variability in morphological characteristics of barley which can be exploited in mixtures.

Spatio-statistical analyses are helping us design the best compromise.

In a very practical way researchers across Europe and beyond are coming together to better understand how to exploit genotype synergies and other parameters in a European Union funded, European Science Foundation managed Cooperation in Science and Technology Action (COST Action 860) 'Sustainable low-input cereal production: required varietal characteristics and crop diversity' (SUSVAR, www.COST860.dk) in which we at SCRI in collaboration with colleagues in SAC are committed participants. Such heterogeneity approaches can be utilised in many crops, and we have cited bioethanol as an example. We have exploited this heterogeneity approach with adapted modern germplasm for malting quality spring barley and demonstrated advantages for the grower, maltster, distiller and the environment. In winter barley we have demonstrated over 15% yield gains. In winter wheat we have also demonstrated quality advantages and industry acceptance for distilling. All these utilised only the genetic variability found in elite germplasm as we grew crops under conventional agronomic practices. However, in collaboration with ADAS we are gaining understanding and developing wheat germplasm with better nitrogen utilisation characteristics for a range of end-users. Fast-track and full exploitation of such germplasm is likely to be in heterogeneous combinations where production systems and end-user constraints permit, assuming the end-users preconceptions have been appropriately challenged.

Plant architecture and structural-functional modelling

A.J. Karley, B.M. Marshall, M. Young, S. Holroyde, G.M. Wright & G. R. Squire

Plant structure-function analysis and modelling are important tools for studying arable communities, and for understanding their impact on crop productivity and arable food web composition. Structure-function analysis involves understanding how plant form, or architecture, influences the way plants interact with their environment. Plant architecture is defined by the three-dimensional arrangement of plant components in space, and determines the way in which plants grow and occupy different parts of the vegetation canopy (Fig. 1). The architecture varies systematically between species and also within species, for example between different crop cultivars or between ecotypic lineages of arable weeds.

Figure 1 The role of plant architecture for community composition in the habitat can be observed in the variety of ways that crop and weed plants occupy, and contribute, to different sections of the canopy.

Knowledge of the 'rules' governing plant structure, and of the variability or plasticity of plant architecture, is important for understanding how plants interact with their environment at molecular, physiological and ecological scales. Variation in plant structure affects the way in which plants compete for and acquire resources, both above- and below-ground. Architectural effects on a plant's ability to capture light, acquire mineral nutrients and take up water all alter patterns of gene expression. At the community scale, plant structure may influence composition and diversity through interactions with other trophic groups, for example plant herbivores and natural enemies.

The ability to quantify plant architecture in three dimensions is therefore crucial for plant structure-function analysis. Traditionally, quantification of objects in three dimensions has been constrained by a lack of adequate tools, but recent developments in digitising techniques have facilitated accurate recording of plant architecture in three dimensions.

Digitising objects in three dimensions: The three-dimensional co-ordinates of plant components can be captured using a dedicated 3D digitiser connected to a PC. The 3D digitiser is composed of a probe, a detector and a pre-processing unit. The probe emits a signal, which can be sonic, magnetic or light. On a sonic digitiser, two spark emitters are spaced at defined distances along the probe, the tip of which is placed against the component to be digitised. When a trigger is fired, the two emitters spark consecutively. The noise created by the sparks is detected by the processor *via* a fixed array of microphones placed alongside the plant. The distances from each emitter to each microphone is calculated from the speed of sound, and this information, together with the known distances between the probe tip and the two emitters, is used to calculate the three dimensional co-ordinates of the plant component.

The way in which the computer software acquires the 3D information is defined by the user so that particular plant components (nodes, leaves, branches, flowers, etc.) can be digitised using a pre-defined set of points that is specific to the plant species under study. For example, the shape of a *Chenopodium album* leaf can be captured using 5 points distributed along the petiole and around the perimeter of the lamina. (Fig. 2)

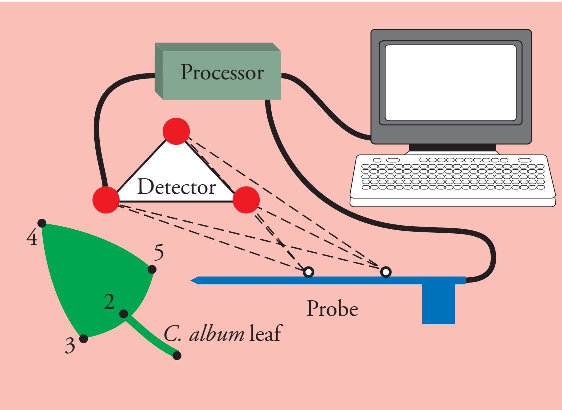


Figure 2 Digitising objects in three dimensions.

Initially, we have captured data on basic plant architecture for several weed species of arable systems. Measurements gathered from digitised plants (Fig. 3) reveal information about the 'rules' that govern plant form, enabling models of plant growth and structure to be constructed and parameterised. Modelling of plant structure in three-dimensional space will be a tool for hypothesis generation and is a critical step towards exploring the interaction between plant architecture and environmental variables, for example, the impact of resource availability or herbivory on resource partitioning. An L-systems approach to modelling plant architecture will be employed

L-systems for modelling plant architecture: *L*-systems, named after their inventor Aristid Lindenmayer, were introduced in 1968 to model the growth of plants. They use a simple symbolic language to capture the basic structure of plants and exploit the repetitive nature of structure to recreate the evolving architecture over time. Consider a plant starting with an apical bud, A. The starting point is known as the *axiom*. At each time step the apical bud produces an internode, F, from which a branch [ ] emanates containing a petiole, P, and a leaf, L. The new structure is terminated with an apical bud. The transformation is known as a *production rule* and can be written as

$$A \rightarrow F[PL]A$$

The plant then evolves by repeated applications of the same rule

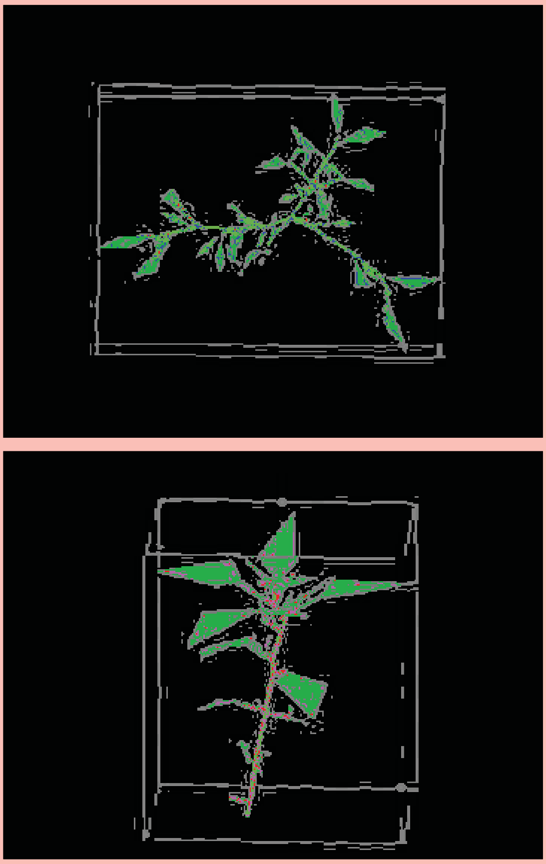


Figure 3 Images of 6-week old *Polygonum aviculare* and *Chenopodium album* plants acquired using 3D sonic digitising equipment.

Time step	Character string
0	A
1	F[PL]A
2	F[PL] F[PL]A
3	F[PL] F[PL] F[PL]A
4	F[PL] F[PL] F[PL] F[PL]A
5	F[PL] F[PL] F[PL] F[PL] F[PL]A

Figure 4 Three plants growing in 3-dimensional space after 5 steps. After each time step the apical bud is rotated through a fixed angle about the main axis to represent phyllotaxis.

The corresponding graphical representation shows the result of this process. (Fig. 4)

The three dimensional architecture can then be used to calculate the local environment of, say, a leaf – how much light is intercepted, whether there is enough substrate to develop another bud or the impact of a pest - and such effects can be fed back to the subsequent growth and development of the plant. It is feasible to observe the evolution of communities of interacting plants and to explore how their differing characteristics confer advantages and disadvantages. Although developed in the 1970's, L-systems can only be used in this way through the increasing power of computers.

Future experimental work will investigate the degree of within-species variation in architecture and test hypotheses about architectural plasticity in response to competition among plants. An exciting possibility involves using architectural data to investigate the genes influencing resource-allocation in realistic conditions. Ultimately, this approach will improve our understanding of the architectural diversity of the arable weed flora and the importance of this diversity for weed-crop interactions and the arable food web.

Acknowledgements.

We are grateful to Dr Dave Skirvin of HRI Warwick for the kind loan of digitising equipment in the initial stages of the project.

Root border cells in plant-soil interactions

A.G. Bengough, P.W. Barlow[a], D.E.L. Cooke, B.S. Griffiths, S.N. Humphris, M. Iijima[b], K.S. Killham[c], S.J. Rodger[d], V.E.C. Stubbs, T. Valentine, & I.M. Young[d]

Background. Root border cells are cells that detach from the root cap and remain in the (rhizosphere) soil adjacent to the elongating root. Border cells often live for a period of days after detaching and they may play a number of physical, chemical and biological roles in the interactions between the root and its rhizosphere environment. Recently it has been proposed that border cells may behave as decoys for pathogenic organisms in the rhizosphere, decreasing the likelihood of pathogen attack on the root tip. Previous work at SCRI has suggested that border cells may decrease friction between soil particles and the root cap surface, decreasing mechanical impedance to root growth. Experiments were therefore performed to investigate both biological and physical interactions in the rhizosphere. The work involved extensive collaboration with the Universities of Abertay, Nagoya, Aberdeen, and Bristol.

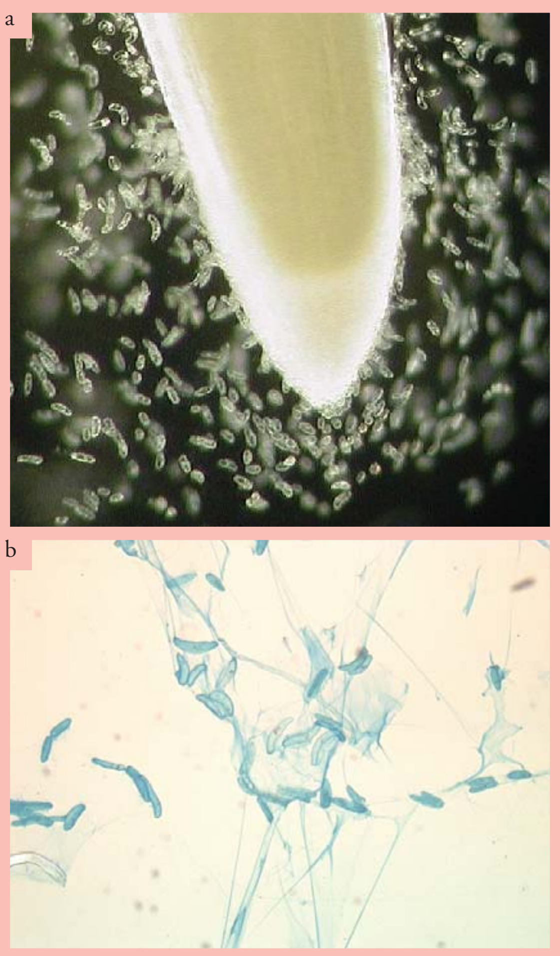


Figure 1 Root border cells (a) in water around root tip, (b) form a network with strands of mucilage from root tip.

Biological interactions. Sets of experiments were performed to study the interactions between maize root border cells and a biocontrol bacteria (*Pseudomonas fluorescens*), a pathogenic fungus (*Pythium aphanidermatum*), a parasitic nematode (*Meloidogyne chitwoodi*) and a bacterial-feeding nematode (*Caenorhabditis elegans*). Experiments were performed on agar, sand, and soil, and involved interdisciplinary collaboration in root biology, soil physics, soil microbiology, nematology and plant pathology.

We performed the first measurements of the uptake and release of carbon compounds from isolated cohorts of border cells using radioactive labelling of glucose. This showed that border cells actively take up and release small quantities of glucose-C [1]. We then assessed the availability of carbon compounds to biocontrol bacteria *P. fluorescens* and *Bacillus subtilis* using reporter gene technology, by measuring the fluorescence of lux-marked bacteria. This confirmed that carbon compounds released from border cells represented only a small source of carbon compounds for the biocontrol bacteria. Of potentially much greater importance is the possibility of these cells releasing specific signalling compounds that influence soil organism behaviour.

For border cells to act as decoys in the rhizosphere they need to affect the direction and speed of movement of their target organisms. Assays of nematode attraction to border cells [2] showed that nematodes were attracted significantly but relatively weakly to border cells. The speed of nematode movement was increased significantly in the presence of border cells and their associated mucilage as compared with control treatments.

Physical interactions - border cells form a disposable sleeve around the root cap. We manipulated border cell and mucilage production by removing the root cap (de-capping) of maize. Several series of experiments were performed to study the effect of de-capping on root penetration into soil, and colonisation by

[a]School of Biological Sciences, University of Bristol, Woodland Road, Clifton, Bristol BS8 1UG
[b]Nagoya University, Crop Science Lab. Graduate School of Bioagricultural Sciences, Nagoya University, Chikusa, Nagoya 464-8601, Japan
[c]School of Biological Sciences, University of Aberdeen, Aberdeen AB24 3FX
[d]School of Contemporary Sciences, University of Abertay Dundee, Dundee DD1 1HG

Figure 2 The use of microscopes to study roots and soil being illustrated at one of the Plant-Soil Interface Programme exhibits at the Institute Open Day.

beneficial bacteria (*Pseudomonas fluorescens*). De-capping decreased border cell numbers by an order of magnitude for a period of 2-3 days, until the root cap regenerated, but did not affect root elongation rates of roots grown on filter paper or agar.

Root growth in loose soil was unaffected by de-capping. In compacted soil, however, root elongation was slowed by about 47% [3], and was associated with an increase of about 67% in the root penetration resistance (pressure exerted by the root to penetrate the soil). The root diameter increased significantly for de-capped roots in compacted soil – also suggesting that roots were experiencing greater mechanical impedance. The most likely explanation is that border cells were acting as a low-friction sleeve around the root cap, decreasing the root penetration resistance.

We next investigated how this sleeve of border cells might influence colonisation of the root tip by relatively immobile soil-bacteria. We studied the distribution along maize primary roots of *Pseudomonas fluorescens,* labelled with Green Fluorescent Protein so the marked bacteria could be tracked and visualised easily. The numbers of colony forming units that were measured in regions along the maize root were affected by de-capping. Presence of the sleeve of border cells in the intact roots largely prevented colonisation of the root tip by bacteria [4]. This was confirmed by direct visualisation of the root tip using confocal microscopy. This suggests that bacteria, being relatively immobile, find it difficult to colonise the root tip, because bacteria located on border cells and their associated mucilage will remain in the rhizosphere as the root tip extends forward into new regions of soil. The presence of this sleeve of cells may therefore prevent the spread of beneficial biocontrol bacteria throughout a root system, in addition to protecting the root tip from pathogens. Colonisation by bacteria was qualitatively similar in compact and loose soil.

Genotypic variation in border cell complement. The potential to select plant genotypes with altered border cell production rates is potentially of interest for both breeding and experimental purposes. We measured the number of border cells present on the root tips of 15 maize cultivars. There was approximately an eight-fold variation (700 to 5600 cells) in this border cell complement per root tip between cultivars, suggesting that very significant variation exists. Such intra-species variation has not previously been observed and is of interest for further study into the mechanisms underlying it.

Acknowledgements. We gratefully acknowledge funding from the Biotechnology and Biological Sciences Research Council, the Scottish Executive Environment and Rural Affairs Department, the Royal Society, and the Japanese Society for the Promotion of Science.

References.

[1] Stubbs, V.E.C., Standing, D., Knox, O.G.G., Killham, K., Bengough, A.G. & Griffiths, B.S. (2004) *Annals of Botany*, **93**, 221-224.

[2] Rodger, S., Bengough, A.G., Griffiths, B.S., Stubbs, V. & Young, I.M.(2003) *Phytopathology* **93**, 1111-1114.

[3] Iijima, M., Higuchi, T., Barlow, P.W. & Bengough, A.G. (2003) *Journal of Experimental Botany*, **54**, 2105-2109

[4] Humphris, S.N. Bengough, A.G., Griffiths, B.S., Killham, K., Rodger, S., Stubbs, V.E.C., Valentine, T. & Young, I.M. (2004) submitted

Belowground effects of transgenic maize

B.S. Griffiths, A.N.E. Birch, S. Caul & J. Thompson

The global commercial area of genetically modified (GM) plants reached 67.7M ha in 2003 and that of GM maize expressing the *Bacillus thuringiensis* toxin (Bt) was 9.1M ha. The potential for effects of Bt crops on non-target soil organisms is considerable, as the toxin is expressed constitutively in all parts of the plant so both plant residues remaining after harvest and root exudates released during plant growth could contain Bt toxin and be incorporated into the soil. Despite the large area of Bt maize, and other crops, and the potential for effects on non-target soil organisms, the number of studies is still relatively small. It was to address this lack of study on the effects of GM Bt-expressing crops on soil populations and processes that the EU-funded ECOGEN project (www.ecogen.dk) was initiated. This interdisciplinary study has followed the advice of previous expert panels in adopting a tiered approach (i.e. laboratory, glasshouse and field experiments) with an emphasis on soil communities and ecosystem functioning. SCRI is one of the partners within the project, with responsibility for mesocosm (glasshouse) experiments which fit into the overall workplan (Fig. 1). Within the ECOGEN project there are four field sites in different European climatic zones (Fig. 2) where Bt maize and a non-Bt isogenic control are grown. While it is clearly essential to compare the Bt crop with its genetically closest available variety to determine whether there are any effects attributable to the Bt variety, it is also essential to be able to put the magnitude of these changes into context. To be able to compare any differences that might be measured between these varieties we also took samples from another, conventional, maize variety. Although a comparison of only three maize varieties is insufficient to cover the range of potential varietal effects it would at least allow some assessment of the Bt variety against non-GM varieties. Finally we also took samples from the surrounding plots of grass, which would allow comparison of the differences due to maize variety, including Bt, with the magnitude of the changes due to growing another common crop. The question then arises whether observed changes due to the Bt trait are ecologically important. In the context of the current land use, and the time-scale of the study, then we would argue that they are not. Yield of the Bt and non-Bt maize was equivalent and, as they had both received the same management regime, the effects of the Bt maize on the soil microbial and microfaunal populations had clearly not affected crop growth. Longer term changes such as the accumulation or depletion of soil carbon, the establishment of a diverse flora should the land be taken out of agricultural production, or the growth of a different crop are beyond the scope of this study. We have demonstrated that our methodology was precise enough to detect differences between treatments and that the differences caused by growing GM maize expressing Bt toxin were not as large as those resulting

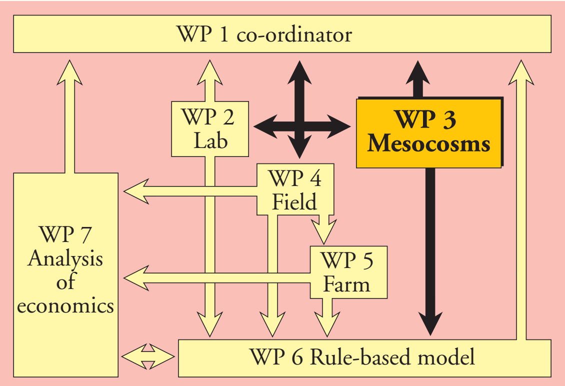


Figure 1 Flow chart to show how the individual components of the ECOGEN project combine. Arrows show the main routes of information and data transfer between workpackages (WP). SCRI has responsibility for WP3.

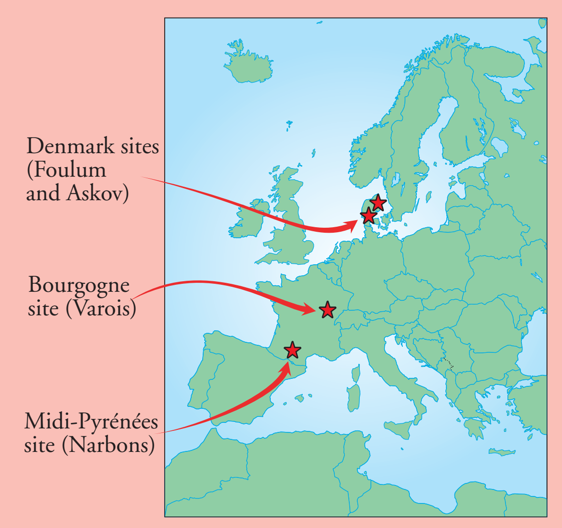


Figure 2 Location of field sites of the ECOGEN project. Two in France and two in Denmark.

Figure 3 Growth of maize in the experimental glasshouse at SCRI. The pots are randomised and include both Bt and non-Bt varieties.

from growing contrasting but conventional maize cultivars, from growing a different crop plant (in this case grass), or as large as natural differences between sites or sampling occasions. We would argue that the Bt effects, therefore, fall within the normal variation expected in these agricultural systems. The mesocosm experiments that we have undertaken include a factorial experiment to determine effects of: soil type (using soil from two of the field plots); Bt or non-Bt maize; and the effects of insecticide (used to control European corn borer in conventional maize crops) on a suite of soil parameters that are also monitored at the field sites. These include: plant growth and Bt content; microbial community structure by both phospholipid fatty acid and community level physiological profiles; microbial biomass; densities and population structure of protozoa, nematodes and microarthropods. Crop growth in the experimental glasshouse was good (Fig. 3), with plants reaching maturity and setting seed as they do in the field. There were no differences in plant performance between the Bt and non-Bt varieties. Results of the soil parameters are still being analysed but indicate large differences due to soil type, consistent with the field data, and some effects due to both insecticide and Bt treatments. Future experiments will be examining a wider range of Bt and non-Bt varieties to determine the likely extent of variation. The single-species tests are designed to quantify the concentrations of Bt toxin that are lethal to a range of representative non-target soil organisms, including protozoa, nematodes, collembola, enchytraeid worms, earthworms and molluscs. Preliminary results suggest a level of toxicity lower than for many commonly applied agrochemicals. The later stages of this 4 year (2002-2006) project will develop decision support tools and economic analyses related to belowground interactions of GM cropping systems.

No sex please: we're British aphids

B. Fenton, A.N.E. Birch, C. Clyne, L. Kasprowicz, G. Malloch. C. Mitchell & S.C. Gordon.

Aphids are amongst the most important groups of insect pests and few crop plants escape the ravages of at least one species. Aphids which specialize on one species or group of plants are described as monophagous. When they reproduce both sexually and asexually on the same plant type, they are referred to as monoeciuos. The European large raspberry aphid, *Amphorophora idaei*, is categorized as monophagous and monoecious. The life cycle of *A. idaei* is shown in Fig. 1A. Eggs are laid on the canes of the European raspberry, *Rubus idaeus,* they hatch in the spring and, as in all aphids, the population expands as a series of asexually reproducing clones. Using genetic markers it is possible to examine the relatedness of neighbouring aphids within and between fields[1]. Fig. 1B shows an example from one of SCRI's experimental fields. Most of the *A. idaei* individuals were genetically different even from those collected from the same part of the same plant. However, one fingerprint did appear at more than one place, suggesting clonal expansion of this genotype. This could have occurred by chance if, for example, the egg of this genotype hatched earlier than others. Overall there were seven genotypes amongst nine individuals collected and tested. This is typical of the genetic variation expected from a sexual population.

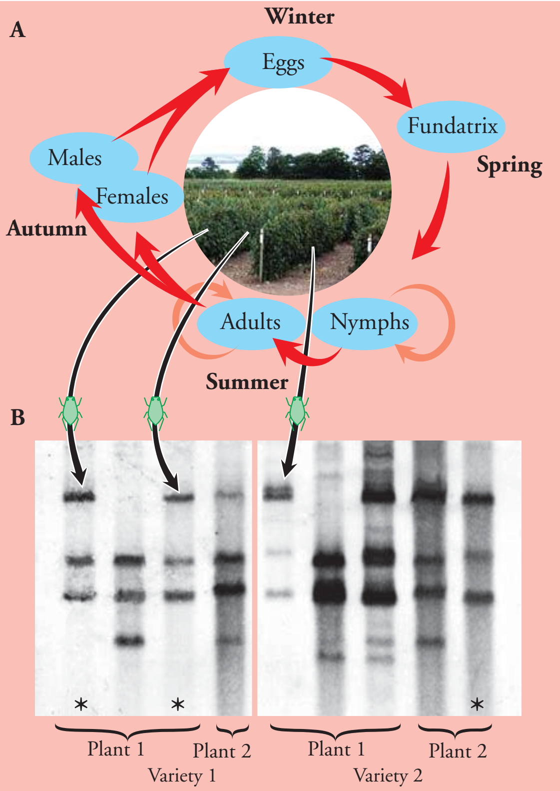


Figure 1 A. *A. idaei* reproduction starts with an egg laid on a raspberry cane. In the spring this hatches to give the first generation of asexually reproducing individuals. Asexual reproduction continues on the raspberry but winged forms (alatae) are also produced and these migrate to other raspberry plants allowing expansion of a clones. In autumn the shortening day length and decreasing temperatures induces the production of specialised sexual forms. These complete the life cycle on the raspberry. **B.** Using genetic markers it is possible to investigate the number of different genotypes in a population. Aphids collected from an experimental field were examined. These came from two different plants on two different varieties. There are clearly many different fingerprints, but one genotype (marked *) was found in more than one place and is probably the result of clonal expansion.

At the opposite end of plant colonizing ability is *Myzus persicae*, the peach potato aphid. This is a polyphagous aphid that can colonize hundreds of secondary host plants. Many of these plants are important agricultural crops. However, like other polyphagous aphid species, the sexual stages of *M. persicae* can only reproduce on one primary host species, in this case peach. The life cycle of *M. persicae* is shown in Fig. 2. Like *A. idaei*, the movement between secondary and primary hosts requires specialized stages, or morphs. *M. persicae* genotypes, which can complete the life cycle by laying viable eggs, are known as holocyclic and those that cannot produce sexual forms as anholocyclic. The males produced by *M. persicae* are winged and can therefore fly from the secondary to the primary host; however, the egg laying females (ovipara) are not winged. To provide egg laying females on the primary host, a specialized migratory winged morph, the gynopara, is generated from aptera on secondary hosts in the autumn and its descendants are the egg laying females. Such an aphid life-cycle which alternates between different summer hosts and the primary winter host is described as diœcious. Restriction of polyphagous aphids to a single primary host has been taken as evidence that their ability to colonize many hosts is a derived characteristic and ancestral aphids were originally specialized.

Eggs are an essential part of aphid overwintering and survival from season to season. Therefore, *M. persicae* should be restricted to areas where peach trees are available for egg deposition, with numbers rapidly declining further away from peach trees. However, this is not what happens and *M. persicae* is a prevalent pest in temperate and colder regions, such as Scotland, where peach trees are very rare and can only be cultivated under glass. In these latitudes it has become clear that *M. persicae* can overwinter through continuation of parthenogenetic asexual summer generations

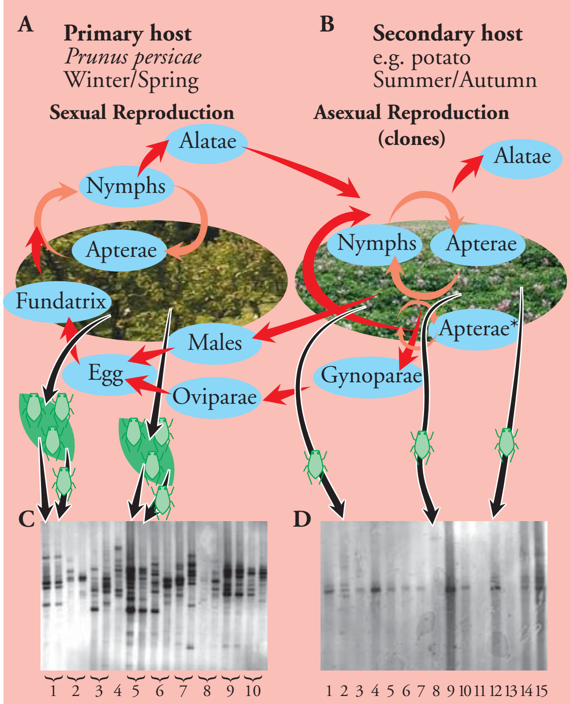


Figure 2 A. *M. persicae* reproduction starts with an egg laid on a peach tree. In the spring this hatches to give the first generation of asexually reproducing individuals. Asexual reproduction continues on the peach tree but winged forms (alatae) are also produced. These migrate to summer crops continuing the expansion of a clone. **B.** On summer crops asexual reproduction reaches its full potential and numbers build up. In autumn the shortening day length and decreasing temperatures induces the production of specialised winged forms. These migrate to peach trees where the complete the life cycle. However, in the winter in Scotland *M. persicae* continues to reproduce using only the asexual parts of its life cycle. **C** & **D**. Using genetic markers it is possible to investigate the number of different genotypes in a population.
In Panel C aphids collected from a single peach tree were examined. The first track contains an analysis of many individuals from a peach leaf and the second track an individual from the same leaf (sample 4 is from a single individual). There are clearly many different fingerprints. This contrasts to the situation in Scotland (Panel D) where there are very few fingerprints.

(see Fig. 2). This is not a general ability of all *M. persicae* clones, and in fact it appears to be restricted to a very small number of regionally specialized genotypes, which have remained dominant in this area for decades. One of the main characteristics of such clones is that they are anholocyclic, that is, they lack the ability to complete the life cycle through egg production. Induction of the latter process would result in resources being wasted in a generation that would require peach trees to continue the life cycle. The result is a paradox which has interested entomologists and evolutionary biologists alike: Why do species that can successfully maintain their populations without sex, continue to reproduce sexually? The reasoning is that sex is an energetically expensive process and any organisms that reproduce without sex should gain an advantage. In the case of aphids sex requires the production of two and sometimes three specialized forms which must colonize one plant species and, once there, they can only reproduce if a suitable mate has found the same location. Males and females have to spend energy in the process of mating and reproduction. In addition, each individual generated from mating will carry only half of the mother's genes. In contrast, asexual females can colonize and reproduce on any suitable plant immediately and their progeny will be, barring mutation, genetically identical to the mother. Therefore, at face value asexual aphid females have at least a double advantage over their sexual peers. The *M. persicae* asexual clones in Scotland support this hypothesis as they have persisted for 20 years although this is still very short on evolutionary timescales. It is possible that entirely asexual species, such as the morphologically distinguishable, *M. antirrhinii*, are long-term asexual derivatives of *M. persicae*, reflecting at least short-term evolution and success for asexual clones. However, it is also possible that asexual aphid populations can be derived in one step through hybridization and *M. antirrhinii* could be a hybrid between *M. persicae* and *M. certus* and there is some molecular and morphological evidence that this is the case.

Two fold cost of sex and advantages of not having sex are likely to be outweighed by the plasticity of an aphid's sexual population. The role of aphids as agricultural pests causing both direct damage and vectoring viruses is well documented and studies to prevent spread occurring continue. One of the biggest problems that applied biologists face when dealing with aphids is their capacity to adapt to new challenges. For example, plant breeding has successfully generated raspberry plants with resistance to *A. idaei* using the single dominant gene A1 from European raspberry. However, within a relatively short time, in evolutionary terms, the population of *A. idaei* has adapted to this source of natural plant resistance. For *M. persicae* plant resistance genes are less important for control and insecticide application is used instead. Throughout the world and in many different crops *M. persicae* is the target of all classes of insecticide. Perhaps because of this, and its potentially large and diverse population, it is one of the most adaptable aphids in counteracting insecticides. There are at least four characterized insecticide resistance mechanisms. One of these involves the amplification of neutralizing enzymes and the remaining mechanisms are based on point mutations in insecticide target sites. Through time the resistance mechanisms have become incorporated into common genotypes.

The ability of sexual recombination to generate new combinations of genes incorporating the necessary local physiological adaptations with genes that overcome either plant resistance or confer immunity to the actions of insecticides is crucial. But, is this scenario the complete picture? In *A. idaei* the adaptive process seems to be repeating itself with the A10 gene, originally from the North American Black raspberry (*Rubus occidentalis*), and now widely used in the *Rubus* breeding programmes at SCRI and EMR. Recent field observations show that some *A. idaei* are able to survive and reproduce on some resistant raspberry genotypes. It is uncertain if these aphids are as 'fit' as those that have overcome the A1 resistance gene and the commercial implications are not fully understood. However, in *M. persicae* the population consists of sexual populations, between which gene flow is frequent, and fragmented local asexual populations such as those in Scotland. The latter populations cannot acquire genes from sexual populations. Thus, for locally adapted asexual populations of *M. persicae* insecticide resistance would require *de novo* mutations, recreating those found in the sexual populations. While the spontaneous mutation rates are likely to be the same in sexual and asexual populations, the spreading process will be much slower in asexual populations. Sexual populations can expand asexually and then different individuals of the same clone can interbreed and lay large numbers of overwintering eggs. Overwintering of asexual clones is likely to result in a decrease in the number of individuals, particularly in a severe winter. It only requires one or two survivors from millions of individuals to start a new season of asexual clones. There are additional problems for adaptation in asexual clones: firstly, the acquisition of multiple resistance mechanisms or physiological adaptations would be so slow that the clone's genes may be subjected to natural turnover long before this is acquired. Secondly, while some mutations may eventually confer resistance, there are likely to be deleterious mutations in many other genes during the acquisition time. There are also likely to be fitness costs to insecticide resistance mutations. In conclusion, sex appears to be beneficial to aphid species, however some long-term asexual clones challenge this assumption. Current research is investigating the ecophysiology and adaptability of these clones.

References

[1]Fenton, B., Birch, A.N.E., Malloch, G., Woodford, J.A.T., Jones, A.T., & Gonzalez, C. (1995) *Scottish Crop Research Institute Annual Report* **1994**, 153-154

Persistence of GM herbicide-tolerant plants

G. R. Squire, C. Hawes, G. Begg, M. Elliott, A. Parish, M. Young, P. Iannetta

Background and purpose The programme's science in whole plants, communities and fragmented populations has in recent years been used to solve several problems of land use and agricultural policy. An important question being investigated concerns the impurities that one type of crop might introduce to another, particularly if one is a GM crop. A GM trait has possible implications for agronomy, ecology, marketability, policy and public interest. It is also relatively easy to trace in and around experimental fields and is useful for getting basic information on mechanisms of survival, spread, success or failure of new organisms in the habitat. Studying the persistence of GM traits needs expertise in a range of specialisms, but without a fundamental knowledge of plants and their environment, such questions of a practical nature could not be answered.

Origin and dynamics GM material in the UK originates from experimental plots or fields of oilseed rape or occasionally from impurities in imported non-GM seed. GM plants have to face the challenges to existence that all plants face in the competitive environment of an arable landscape. At harvest, some seed drops to the ground, where much of it is eaten by animals, attacked by fungi or killed by drought or frost. Any survivors entering dormancy remain in the soil until they die or receive signals to make them germinate or emerge, when they compete with weeds and crops. If in flower, they may receive pollen from other oilseed rape, so their offspring become 'diluted', or they may donate pollen to other plants. Our findings show there is little ecological effect of this GM seed, unless it becomes advantaged by circumstances – for instance, if herbicide tolerant plants are sprayed with the herbicide to which they are tolerant. Agronomic or economic problems may arise from the buried seed that emerges in later oilseed rape as volunteer plants, or gets moved around the country in machinery. Under present regulations, a grower will be unable to market a crop as non-GM if it contains GM seed above a specified threshold, either 0.5% or 0.9% depending on circumstances. We have said before that it will be difficult, but by no means impossible, to manage oilseed rape volunteers so as to be certain of keeping the presence of GM below such a threshold in a field that has recently grown a GM crop of oilseed rape. We are now examining fields to estimate the percentage presence of GM in soil, crop and yield, and to find which factors of the environment, genetics and agronomy can be manipulated so that impurities remain below a threshold.

Figure 1 Section of field (9 x 9 m) following glyphosate spray showing clumped arrangement of surviving oilseed rape individuals (symbols) and dead, dense weed vegetation (shading).

Detection and estimation Detecting presence, or estimating percentage presence, faces difficulties of sampling and diagnostics. Many samples need to be taken from a range of locations in a field in order to 'capture' the distribution in space of the GM and non-GM populations. Volunteers are likely to be highly clumped (aggregated), especially if they came from GM plants which themselves arose as impurities in an otherwise non-GM field. In an example in Fig. 1, volunteers tolerant to the herbicide glyphosate were identified because they survived when glyphosate was sprayed on the field. They probably arose as impurities in non-GM seed sown the previous year. Most of the individuals were arranged in two clumps, each possibly originating from seed shed by single GM plants at the previous year's harvest. Statistical methods exist to account for such clumpiness, but the more clumped the distribution, the more samples have to be taken and processed to estimate the percentage impurity.

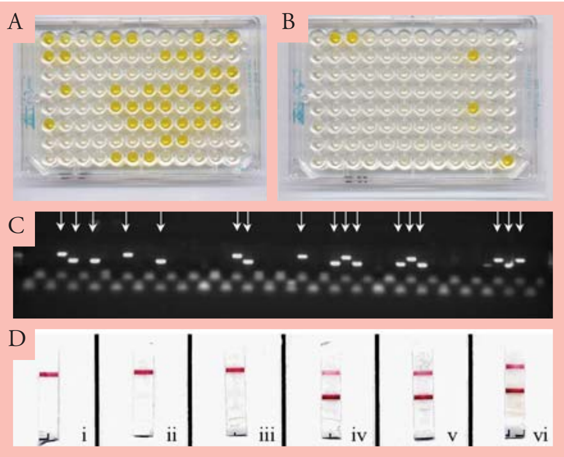


Figure 2 Examples of detection methods for GM herbicide tolerance in oilseed rape. A and B show ELISA results for leaf tissue, 96 leaf samples having been tested in each plate, GM individuals identified by the presence of a yellow colour; note GM presence is clearly lower in B than A. C shows PCR results from DNA extracted from 48 leaves; GM presence in 17 leaves produces a bright band and is indicated with an arrow; samples not containing GM material are invisible. D, lateral-flow (dip-stick) test results: sample i-iii showing a single red band indicate absence of GMHT; GM tissue produces a second (lower) red band.

Detection is usually possible by one or other of several techniques. For herbicide tolerance, rapid screening of very large populations by spraying with the herbicide can be used as a preliminary screen, but is not always reliable. Whether the plants are GM or not, they differ in their ability to survive a spray, depending on the developmental stage of the plant. So some GM volunteers might die in response to spray, thereby lowering true GM levels, or non-GM volunteers might survive. SCRI also uses a range of "off the shelf" and "in-house" techniques to test leaf or seed samples for the presence of the transgene itself (the DNA) or the protein it produces. For detecting GM glufosinate ammonium tolerance, proprietary antibody methods such as the lateral flow "dip stick" test or ELISA (Enzyme Linked Immunosorbant Assay) are used routinely, as are in-house PCR (Polymerase Chain Reaction) tests for the presence of the transgene (Fig. 2). Even molecular methods sometimes have potentially large error frequencies. Plant material grown in the field can vary markedly in its biochemistry to a degree that might confound the reliability of PCR in detecting a transgene. SCRI is undertaking tests to identify the most robust techniques that are capable of providing true rates of the occurrence and persistence of GM oilseed rape.

Conclusions Attempts to understand why and how feral and volunteer plants persist is telling much about plant population dynamics generally. The agronomic questions referred to above can be answered, but we do not yet know whether it will be practicable to switch between GM and non-GM cropping in the same field. To reiterate, the presence of GM herbicide-tolerant plants does not appear to affect the ecological safety of the field, but their presence in a later crop may make it unmarketable as GM-free. The programme has recently won new funding from Defra to examine persistence, specifically at sites where GM crops were trialled in the UK.

Biomathematics and Statistics Scotland (BioSS)

D.A. Elston & J.W. McNicol

Biomathematics & Statistics Scotland (BioSS) provides quantitative support for the SEERAD research programme. This is achieved through a dispersed group of statisticians, mathematicians and computing experts based at BioSS centres in Edinburgh, Dundee, Aberdeen and Ayr. The distributed staff structure fosters communication between BioSS's quantitative experts and researchers in other disciplines. BioSS staff support SEERAD-sponsored research projects led by scientists at the five SABRIs and SAC at many different levels, ranging from infrequent advisory sessions through to collaboration as equal partners. BioSS also has three research themes, namely Statistical Genetics and Bioinformatics (led by the BioSS group at SCRI); Spatial and Temporal Models; and Systems Modelling and Risk. These research themes allow BioSS to address quantitative problems arising from SEERAD's research programme at a generic level, leading to an improvement in the quality of research outputs from the Sponsored Bodies.

In molecular sequence analysis, we have produced user-friendly software for the detection of recombination. TOPALi is a Java graphical analysis application that allows the user to identify recombinant sequences within a DNA multiple alignment either automatically or via manual investigation. TOPALi allows a choice of three statistical methods, developed previously by BioSS, to predict the positions of breakpoints due to past recombination events. The breakpoint predictions are then used to identify putative recombinant sequences and their relationships to other sequences within the alignment. In addition to its sophisticated interface, TOPALi can import many sequence formats, estimate and display phylogenetic trees (using Neighbour-Joining or Bayesian approaches) and allow interactive analysis and/or automatic HTML report generation. TOPALi is freely available from the BioSS website.

We used multivariate analysis and geostatistical approaches to study microbial community structure in upland grasslands as part of phase 3 of the SEERAD funded Micronet project. We were able to establish that there were different drivers for rhizoplane bacterial and arbuscular micorrhizal (AM) fungal community development and that the scales of influence were different. Rhizoplane AM fungal community structure was mainly influenced by the associated plant type and by the composition of proximal vegetation (within 1 cm). Rhizoplane bacterial community structure was influenced by the composition of vegetation in close proximity (also within 1 cm) but the plant type to which the community was directly associated had little effect. We also showed that bacterial community structure was influenced by factors operating at larger scales (up to 6 m). This was not the case for AM fungi.

Simulation work on the use of linkage disequilibrium mapping in barley populations showed that the transmission disequilibrium test (TDT) is effective in locating genes controlling traits when specially constructed populations are used. These populations require the generation of heterozygote parents as would result from the cross of two inbred lines. The F2 from such a cross provides sufficient offspring with heterozygote parents to track the flow of marker alleles from one generation to the next. The TDT can then be used to highlight associations between markers and traits.

Experience with multiple testing of microarray target data and compounds from metabolic profiles led us to investigate methods of estimating the False Discovery Rate (FDR), one of the error rates associated with tests of significance. A new method, based on modelling the density function of significance values as a Uniform+Beta mixture distribution, was developed and is now incorporated into routine analyses of ‘omics data.

Collaborating with SCRI scientists, BioSS co-developed a comprehensive decision-support web application to assist Dutch farmers in potato cultivar selection, with the primary emphasis on Potato Cyst Nematode (PCN) management. Mathematical models of PCN population dynamics were modified to take account of the nature of current PCN infection in the Netherlands. Farmers interacting with the website supply historical details of field PCN levels which act as a reference baseline for the models, which ultimately provide them with predictions of future PCN population densities and potato yields in both graphical and textual formats.

Research services

Analytical facilities

C.M. Scrimgeour

Organic mass spectrometry SCRI currently has seven 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 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. This instrument is to be upgraded to the TEMPUS 2 specification during 2004 and a second TEMPUS 2 has been ordered. Until this is installed a Finnigan TRACE DSQ has been installed as a temporary measure.

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 SSQ 710C 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.

ThermoQuest LCQ-DECA LC-MS system.

Media Kitchen

W.A. Ridley

The Media Kitchen has been operating since 1996 and provides a wide range of sterile microbiological, mycological, plant tissue culture, media preparations and disposable plasticware for the Institute's laboratory staff.

The advantage of buying in bulk has meant huge savings and prices have hardly risen over the last eight years. The Media Kitchen operates as a research facility under the central administrative overhead, to minimize bureaucracy. Centralising the Media preparation has meant that individual departments no longer have to maintain a sterilization 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 and have been here since the start-up in 1996.

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 and empty tip boxes and Eppendorf pots are collected to be refilled. This work is carried out primarily by the support workers who 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 and we aim to meet all requests within 24 hours. Figure 1 shows the output of the Media Kitchen since the first full year in 1997.

The Media Kitchen outgrew its original premises and moved to much larger premises in September 2000. This much improved facility has given us greater diversity and much more space for holding stocks of media. This relieves the pressure if we are short-staffed.

The work that is carried out in the Media Kitchen frees the innovative scientists, visiting workers, PhD students and support technicians from the repetitive and time-consuming tasks associated with Media Preparation. It also guarantees a standardized quality of media according to ISO 9000. This was attained in November 2002 and is vital regarding grants and contracts.

The facility and service provided by the Media Kitchen is appreciated and often envied by visiting scientists and students. The provision of a standardized, quality assured media and sterile disposable ware facility and the daily removal of waste microbiological materials is now well established at the Institute and is invaluable to researchers and to those monitoring costs and assessing value for money.

	1997	1998	1999	2000	2001	2002	2003
Boxes of tips (100/box)	13,933	14,300	19,738	19,653	20,609	24,000	21,480
Eppendorf tubes (*c.* 200/pot)	2,600	2,620	4,211	4,279	4,130	4,561	4,690
Agar plates	37,011	43,600	56,084	52,064	51,349	50,974	50,477
Other items *	24,654	45,080	47,928	51,850	43,389	43,180	37,593

* 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 '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 83 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 glasshouses and controlled environment facilities. In doing so they produce consistent, high quality results for scientists whose work is increasingly detailed and accurate.

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 equipment required by the science programmes. The Institute was successful in attracting over £2.5 million of capital grant from the Scottish Executive Environment and Rural Affairs Department, and much of the new equipment requires more sophisticated support and maintenance. The staff have become extremely adaptable and knowledgeable in the provision of these services, 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 Information Technology Unit and its development is central to the Institute's activities. The Institute has invested in an Institute-wide information management system to allow it to manage the ever increasing flow of information, to provide an effective and efficient environment for staff to manage their work, and enable staff to develop the Institute web site, 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 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 presentations 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 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. The Institute is now accredited to ISO 9001 standards, and work is under way to achieve accreditation under the ISO14001 standard.

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 Human Resources 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 Human Resources 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.

Scientific Liaison and Information Services

I.R. Pitkethly, S.J. Neilson, & S.E. Stephens

This year saw a consolidation of the services offered by Scientific Liaison and Information Services (SLIS). The goals of publicising the work of the Institute and raising its profile were pursued. The Visual Aids Unit continued to provide top class posters, publications and photographs and the website took on a new and better look. Many visits and exhibitions were organised and the Education Officer was enthusiastic in her mission to take SCRI's research into schools. The Library continued to provide information at the desktops of those needing it.

Visits to SCRI were encouraged and tailored to the requirements of the group visiting. These included groups of university students both from Scottish and overseas universities. One of these was the product of close liaison between Dundee University Medical School and SCRI where the students learnt about the beneficial attributes of fruit and how plant breeding can contribute. School students came to see and get direct experience of laboratory work. Growers from a variety of countries visited. Societies including the Scottish Rhododendron Society, and Young Farmers visited to see experiments in the field and hear from the experts. Politicians and international delegations were also made welcome.

SCRI was represented at the Dundee Food and Flower Show with a very informative display on the history of the potato and the current potato breeding programme; samples of the *Solanum phureja* variety Mayan Gold were given away for the public to try at home. Potatoes were also in the spotlight at 'Potatoes in Practice', back out in the field by popular demand. The British Potato Council-funded trials of SCRI and the Scottish Agricultural College were demonstrated and poster displays of topical issues such as blight, Potato Cyst Nematode and powdery scab control were mounted. The Scottish Society for Crop Research sponsored fruit walk was expanded to a bigger event 'Fruit for the Future' with seminars as well as the popular new variety tastings and walk around the fruit trials. SCRI and MRS had a stand at the Royal Show in Stoneleigh, this show attracts international delegations and gave us the opportunity to raise our profile world-wide. The posters provided by Visual Aids at these events made the job of attracting people to the stand far easier.

The Education Section of SLIS has presented or facilitated displays, activities and demonstrations to schools, school visits to SCRI and talks to primary and secondary schools throughout Angus, Dundee, Perth and Kinross, Edinburgh and Lothians, Aberdeenshire, the Isle of Skye and Ninestiles Technology School in Birmingham. Educational themes have also been presented at local and national festivals and science fairs. A teachers' continuing professional development (CPD) day was held at SCRI and we have been working closely with Scottish Executive education organisations and facilitators to assist with the current curriculum guidelines review materials. In total, more than 5,000 schoolchildren and teachers have been reached by these events.

The Visual Aids Unit continues to provide a comprehensive service in presenting the work of the institute in publications, at specialist and public events and online. For example 3,000 photographs were taken and 160 scientific posters were made for presentation around the world. A calendar featuring SCRI photography was designed and sold for charity. The redesigned and restructured website went live and now receives 27,000 visits per month.

The profile of the Institute's environmental work was greatly enhanced by attaining the status as a Linking Environment and Farming (LEAF) Innovation Centre. This attracts a different section of the general public and provides different topics for engaging with farmers. The in-field experiments related to LEAF topics have provoked a great deal of interest. An area of the SCRI estate has been selected for a new, educational garden called the Living Field Community Garden. The garden links science, agriculture and the environment and will be an integral part of future SCRI outreach activities to both schools and the general public.

The Library service was disadvantaged by the Librarian taking on the role of Deputy Head of SLIS but was compensated for by the appointment of a Library Assistant; it is to the credit of the staff that there was no diminution of the service. Access at scientists' desktops to scientific publications has made library use much easier and the usage logs show how much the service is appreciated; high use of the scientific literature is an indicator of a healthy research environment. Although there is access to electronic journals published by Elsevier, Blackwell, Nature Publications Group and Science the number of interlibrary loans has dropped very little.

Information Technology

B. Marshall & S. Clark

The SCRI Information Management System (SIMS) was rolled out in Summer 2003 (Fig. 1). It represents a major change in the Institute, both in the technology and culture. The three major components, Exchange 2000, Sharepoint Portal and Activediton Content Management System (CMS), all run on Microsoft 2000 Advanced Servers. A basic email service provided by Pegasus Mail is replaced with a comprehensive collaborative tool incorporating advanced email facilities, shared diaries and tasks, and on-line organising of meetings and resources. Every PC in the Institute was visited, brought up to appropriate patch levels, Outlook 2002 installed and older systems decommissioned. Sharepoint Portal Server provides a single point of access to all electronic information in the organisation. It replaces the traditional intranet - simple web pages with limited access for updating. The Portal enhances the efficacy with which information is shared and is inclusive; all staff are encouraged to contribute. Currently its main functions are to manage documents (version control, quality assurance through approval, advanced search facilities for retrieval) such as policy, health and safety, committee and theme, programme and project documents, electronic forms, funding opportunities and announcements. The CMS provides a means of maintaining a common style throughout the SCRI's Internet and Intranet web-sites, while allowing non-specialist staff to enter content directly from their desktops using a simple word-processing-like editor. Traditionally, all information had to pass through a single person to ensure a common style. As the migration to the new site progresses, Visual Aids are able to focus on the quality, design and timeliness of content rather than transcribing content for others, and widen the role of the web for SCRI in knowledge transfer.

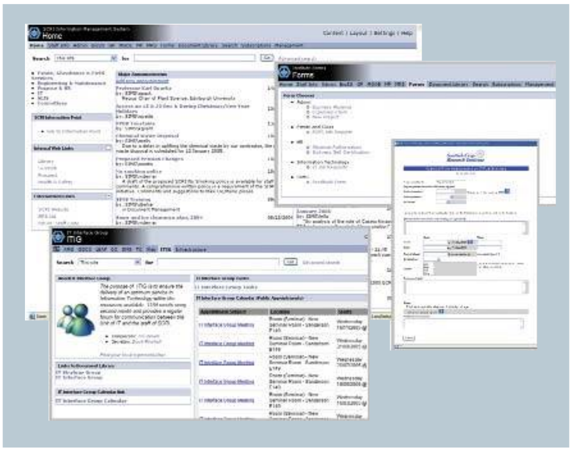


Figure 1 SIMS (SCRI Information Management System) A single point of access which includes document management, announcements, electronic forms and committee workings etc

Training is essential for effective uptake. A comprehensive programme was carried out in the summer of 2003. There were three courses: an overview of the SIMS concepts, the use of Outlook and finally the SIMS Portal navigation and document management. Over 90 per cent of all SCRI staff attended. Outlook was an instant success, with staff being switched over during their training sessions. The Portal has taken longer but is now the preferred location for all formal documents, electronic forms, all new announcements and committee information. The functionality of SIMS will continue to evolve, driven by the needs of the organisation and as staff become more familiar with it. Future training and developments are being lead by the SIMS Champion group which includes Paul Grimmond, our new SIMS systems administrator bringing fresh ideas from industry.

Software compliance is a serious issue. Recent cases of illegal software use have resulted in large fines being charged to the offending organisations. SCRI reviewed its policies and procedures in consultation with the Federation Against Software Theft (FAST). Monitoring software is a key and challenging activity of compliance. The Centennial software auditing tool was purchased. It checks all systems connected to our network and informs us of all new software installed since last audited. Raising user awareness of the issues and their responsibilities is also important.

The Institute continues to invest in the infrastructure of IT. The central data switch was upgraded and a new blade purchased with a further sixteen gigabit fibre optic interface. Most of the remaining, more remote buildings are now connected at this higher data rate and the last of the external laboratory buildings upgraded to Category 6 cabling. The upgrade to Netware V5.1 network operating system was also completed. However, with the introduction of the

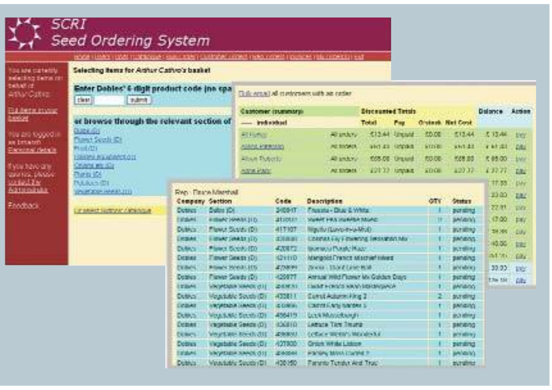


Figure 2 SCRI's on-line seed ordering where profits go to charity. An Honours Project in Computer Science with the University of Abertay.

Microsoft server platform for SIMS the longer term future of Novell at SCRI is uncertain.

Our collaboration with the Computing Honours Projects at the University of Abertay continued to be a fruitful source of new developments. Two new web-database applications were delivered to SCRI. One provides staff with an on-line means of placing job requests and tracking their progress, while IT staff address them and review the nature and scope of jobs that arise. The second provides staff with an on-line means of ordering seeds (Fig. 2). This is a long established service which offers staff significant discounts with "profits" going to charity. Historically, it involved considerable manual effort, now gone.

Finance and Human Resources Unit

N.G. Hattersley & A.C. 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 £2.57 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 accounts staff process many thousands of purchase invoices per annum, 95% of which are paid within 30 days, and over 1,000 sales invoices are raised as well as claims on grant aided projects. In addition to the 'core' research projects funded by the Scottish Executive Environment and Rural Affairs Department, further income is obtained from other external grant awarding bodies and from industry. The Institute carries out research on about 200 projects which are monitored and supported by the accounts team, and the Institute can also act as the co-ordinating partner for certain collaborative projects. The accounts team also maintains several thousand items on its fixed asset register, ranging from personal computers to laboratory buildings.

The Institute is dependent 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 overhead expenditure are critical to the management of the Institute and its ability to produce world-class science in a competitive research environment. The role of budgeting and forecasting has become increasingly important to maintaining the financial integrity of the Institute.

The Human Resources (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.

HR works with the Senior Management Team to develop a Manpower Plan to meet the needs of the Corporate Plan and ensure the effective recruitment of the staff required. In 2003/04 (1 April 2003 – 31 March 2004) this included 47 posts advertised which attracted 210 applications from external and internal sources. HR is also responsible for the operation of the induction 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 effective performance management is carried on throughout an individual's 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.

Estate, Glasshouse & Field Services Unit

P. Gill, G. Pitkin & E. Caldwell

Graham Pitkin attended the International Controlled Environment Conference, 'The Power to Control', which was held at the University of Queensland's Bioscience Precinct in Brisbane, Australia during March 2004. Topics ranged from small to large scale Controlled Environments (growth cabinets, growth rooms and glasshouses) used by CSIRO and the Australasian universities. There were also presentations from NASA on bio-regeneration life-support systems used in space exploration. About 100 delegates attended from the Pacific Rim States, North America and Europe.

Glasshouse Section Construction of the latest phase of the general-purpose glasshouse complex began in 2003. This will provide a mixture of cubicle sizes from 13 m^2 to 75 m^2 housed within a double-winged 'Venlo' glasshouse. Facilities and service specification are similar to the earlier phase but with an upgrade of supplementary lighting to a minimum PAR of 150 $\mu mol.m^{-2}.s^{-1}$ at the top of the crop canopy.

Two new 12 m^2 growth rooms were commissioned in February. They each have 6 m^2 of benching which can be adjusted to maintain a constant irradiance at the shoot apices of 600 $\mu mol.m^{-2}.s^{-1}$. The HPI/tungsten light source provides a good spectral balance for growing barley plants, which are used in anther culture, isolated microspore and transformations.

About twenty children participated in the annual 'Bring your child to work' day held in the spring. They were shown how the weather is recorded at the meteorological site and had the opportunity to mix their own compost and sow flower seeds.

Aerial view of new general-purpose glasshouse complex.

Glasshouse staff assisted with the potato demonstration at the Dundee Flower & Food Festival held in September. The exhibit included the collecting of wild species from south and central America which are retained as part of the Commonwealth Potato Collection. These species are used in the breeding programme as sources of pest and disease resistance and added health and nutritional benefits.

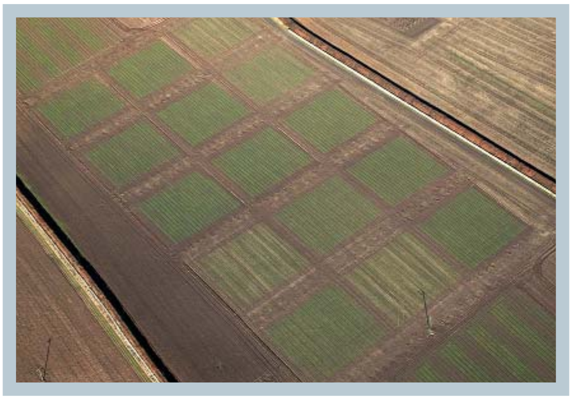
Two contracts undertaken entirely by the glasshouse staff are germination tests of oilseed rape selections and the production of game-cover plants for The Game Conservancy Trust for display at Scone, Kelso and the Black Isle agricultural shows.

Field Section Work started in early 2004 to convert a muddy 0.15 ha field site into an educational resource aimed at the local community and schools. 'The Living Field Community Garden' will show the links between science, agriculture and the environment by the use of demonstration plots, interactive exhibits and information boards. The site will include a small pond, with adjacent bog area, and a wild flower meadow with hedges and trees to provide shelter for a variety of birds and insects. This initiative complements the institute's other environmental and sustainable agriculture activities.

As a LEAF Innovation Centre, a series of display boards on food webs, beneficial organisms and pests and diseases have been erected at strategic points within the institute as part of the Invergowrie Path Network initiative.

Various projects under the Countryside Premium Scheme were continued and extended, including tree wind-breaks, species-rich grassland, beetle banks and mixed native hedgerows. The presentation of experiments was improved by the grassing of field roadways, reducing the need for herbicide sprays and enhancing the biodiversity within the grass sward.

A soil disturbance trial was begun as an extension to the cereal breeding programme and compared five different methods of soil preparation prior to sowing. These included zero tillage (no soil disturbance), minimum tillage (light cultivation and discing), traditional ploughing with pressing, deep ploughing with



Aerial photograph of tillage experiments

pressing and traditional ploughing followed by soil compaction. Field staff worked together with manufacturers of commercially-available equipment following discussions held at the 'Tillage 2003' event held in North Yorkshire.

Several items of new equipment were purchased including a long-wheel based, crew cab Land Rover together with trailer for transporting tractors and equipment to off-station experimental sites. The acquisition of a narrow vineyard tractor will make an important contribution to operations within the soft fruit tunnel area and a new air-assisted sprayer will improve pesticide application and minimise chemical drift.

In preparation for the proposed Science Park, over 10,000 blackcurrant plants were transplanted from South Bullion to Laboratory field between late November and February, when plants were dormant. These large, mature bushes were each excavated with a large root ball to minimise establishment losses at the new site. The operation was exacerbated by adverse weather and poor ground conditions but no plants were lost during the process.

New strawberry and raspberry advanced selections were planted in the Spanish tunnels during the spring for assessment of their potential under commercial protected cropping regimes.

Two contracts are undertaken exclusively by field staff, including the biomass accumulation of grasses and the performance of a range of fleeces and their effects on potato yields.

Engineering & Maintenance

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.

SCRI Reception

During 2003 projects undertaken included complete refurbishment of three laboratories and eight offices plus upgrading of our Human Resources and Reception areas. 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, voice evacuation and data/telephony cabling systems.

High efficiency condensing boilers were installed in each of the main laboratory buildings as the first step in phasing out dependency on the central steam boiler plant.

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 those 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 Institute's estate unit in order to keep its large fleet of farm vehicles and machinery in good order.

Mylnefield Research Services

N.W. Kerby & J. B. Snape

MRS, the commercial wholly-owned 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 and continued to benefit SCRI through Gift Aid and the provision of services, without any external financial assistance.

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. During the last four financial years MRS has gifted in excess of £1 million to SCRI and its affiliated charitable trust, the Mylnefield Trust.

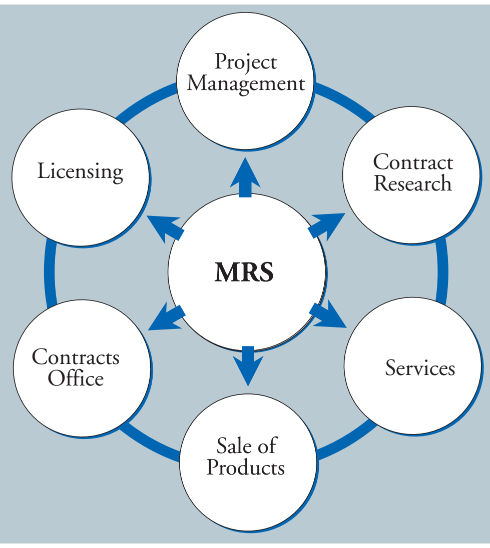


Figure 1 The business activities of MRS.

The business activities of MRS are diverse (see Fig.1) and its major sources of income (2003-2004) are:-

Contract research (68%) - In the financial year 2003/2004 MRS signed a total of 19 contracts with a total value of £1,435,227.

Royalties and licence fees derived from commercialising IP (15%)

Analytical services and consultancy (10%)

Sale of products (7%)

In recent years, the proportion of income from contract research has fallen from approximately 90% of turnover to approximately 70% and this is a reflection of the turbulent agricultural and "ag-biotech" markets that have been discussed in previous annual reports.

Finances The income of MRS increased slightly to £1.67 million in 2003/2004. However, charitable donations increased significantly, totalling £185k (£115k to SCRI and £70k to the Mylnefield Trust) in 2003/2004 as compared to a total of £145k in 2002/2003 and were greatly in excess of budget.

The Lipid Unit is ISO9001-accredited and is operating to GLP standards. There was significant growth in lipid analysis business in 2003/2004 and MRS continues to explore new avenues of business for this unit. Two successful training courses were held in 2003/2004 on lipid chemistry and analysis. The Lipid Analysis Unit turnover was in excess of £204k in 2003/2004.

MRS aims to receive annual royalty income from its plant varieties and inventions of at least £180k, this was exceeded in 2003/2004 with an income of £226k.

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. In 2003, MRS decided not to renew the subcontract it had with a third party for the commercialisation of the Glen Ample, Glen Lyon and other raspberry varieties and these are now commercialised directly by MRS. One of the challenges MRS faces for these varieties is the collection of royalty income from territories such as Spain. To facilitate this MRS appointed Eurosemillas as head licensee for Spain. Eurosemillas has gained expertise in this market through the licensing of the University of California strawberries in Spain.

One of the strategies in the current MRS business plan was to investigate the feasibility of licensing IP from other organisations on their behalf. Investigation showed that this would maximise benefit from MRS's in-house expertise and led to MRS successfully tendering in 2004 for the position of Programme Agent to the English Raspberry Breeding Programme housed at East Malling Research.

MRS licences potatoes, forage and salad rape, turnip, kale, blackcurrants, blackberry, raspberry and strawberry varieties and currently has a portfolio of around 450 licences.

In the financial year 2003/2004, two potato varieties and two swede varieties were entered into National List trials, and three potato varieties were granted European Plant Variety Rights (Inca Sun, Tay and Mayan Gold).

Raspberry Breeding The raspberry breeding programme signed in 2003 and funded by the Horticultural Development Council, the Scottish Executive, the Scottish Society for Crop Research, and a consortium of all major companies involved in the raspberry industry in the UK is progressing well and it is expected that EU Plant Variety Rights will be sought in 2005 for at least 2 new raspberry cultivars.

LINK Programmes MRS, together with SCRI, are involved in two new LINK projects. The first (Drs. Bryan, Bradshaw and Griffiths) is investigating the genetic and chemical basis of potato flavour, especially looking at flavour profiles of SCRI-bred phureja varieties. Eventually, it is hoped that new potato varieties with improved, and a wider range of, flavours could be bred. The second project (Dr Graham) builds on previous work at SCRI to develop the first genetic linkage map of raspberry and aims to develop a molecular marker for raspberry root rot. This marker could be utilised in the SCRI raspberry breeding programme (see above) and lead to the release of new cultivars with resistance to this economically devastating disease. Together these two programmes will enable SCRI potato and raspberry breeding programmes to remain at the forefront of international plant breeding.

Developing Markets In order to consolidate our business and recognise the increasing competition in the fields of contract research and licensing MRS has started to develop new markets for our products and services. Details of some of our activities are highlighted below:

CHINA is the biggest producer of potatoes in the world by area (24% in 2004; ~4.6m ha of harvested crop). Between 1990 and 2004 potato production more than doubled from 32m to 75m tonnes. However, yields are substantially lower, as compared to UK, at an average of 16.3 tonnes per ha. China is the second largest potato seed market. However, the UK is currently not allowed to export its high quality seed potatoes into China because of a ban imposed by the Chinese government. The China Britain Business Council (CBBC) organised a trade mission to China in 2002. MRS together with colleagues from the British Potato Council (BPC), CBBC and Defra

Professor J. Hillman and Dr. N. Kerby at the World Potato Congress in Kunming.

played an active part in the initial negotiations to develop an inter-government agreement between the UK and China on plant health. Defra Secretary of State, Margaret Beckett, and the Chinese Minister of Agriculture, Du Quinglin, signed the agreement on 15 June 2004 and this is the first step to lift the ban on UK potato exports to China. The next step is for the General Administration for Quality Supervision, Inspection and Quarantine (AQSIQ) to conduct a "pest risk analysis" based on information supplied by UK authorities. SCRI hosted a visit of a senior AQSIQ delegation during summer 2004 and we currently await the finalised regulations. The UK seed industry will have a significant opportunity when the ban is eventually lifted since the UK has some of the highest potato seed standards in the world and Scotland is free from brown rot and ring rot. Our first joint venture, Scottish Potato Technology (SPT) Ltd, should be well placed to exploit this market and we hope to see SCRI varieties exported to China where protection of IP has been sought for a SPT controlled cultivar.

China hosted the World Potato Congress (WPC) in March 2004 in Kunming, Yunnan Province and Nigel Kerby gave one of the plenary lectures. SCRI, MRS and SPT exhibited on the British stand organised by the British Potato Council. At the WPC a Memorandum of Understanding in the field of collaborative potato research between SCRI and the International Potato Centre (CIP) was signed. Additional work in China included setting up of trial sites in China for blackcurrant varieties (Ben Tirran, Ben Hope and Ben Alder) and recently an Agreement has been signed with the Agricultural University of Jilin for further agronomic evaluation of these varieties.

INDIA SCRI hosted the visit of Dr Paul Khurana, the Director of CPRI Shimla, and Dr M Rai (Director General, Indian Council of Agricultural Research) in August 2003. Following on from this visit, a Memorandum of Understanding for collaboration in potato research is being negotiated, and scientific exchanges have been planned.

EASTERN EUROPE The enlargement of the EU on 1st May 2004 to include the Baltic States, Czech and Slovak Republics, Hungary, Poland, Slovenia, Malta and Cyprus has made it easier for MRS to develop this large and expanding market. In advance of this historical event, MRS had already licensed blackcurrant varieties in Poland, the Czech Republic and Slovak Republic. The blackberry variety, Loch Ness, is licensed to be grown in Hungary and sold throughout Eastern Europe, including the Baltic States, Poland and Slovenia. Symphony, the popular SCRI strawberry, is being grown commercially in the Czech Republic and Hungary. MRS has established collaborations with key research institutes in Romania, a candidate country for entry to the EU. In addition to a number of consultancies looking at the potential for organic agriculture in Transylvania, SCRI-bred varieties of potato and soft fruit are being trialled with a view to establishing commercial production in the near future.

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, Higgins G&I Ltd, Mylnefield Holdings Ltd (on behalf of SCRI and MRS), Reekie Manufacturing Ltd and Scottish Agricultural Science Agency.

Products and services include:
- Sale of high grade seed
- Micro-propagation
- New varieties and plant breeding
- Machinery (field and grading)
- Storage systems
- Advisory and consultancy services
- Disease diagnostics
- Seed certification
- Agronomy
- Technology
- Contract and collaborative research

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 outwith 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. Dr Jonathan Snape formerly the Commercial Manager of MRS was appointed as Commercial Director. Ms Lynne Ferguson was appointed in September 2003 as an Assistant Raspberry Breeder and also Mr Lee Hunter was appointed as an Analytical Chemist within the Lipid Unit. MRS retained the IIP Standard in November 2003.

Knowledge Transfer and Exploitation (KTE) has been central to the vision and strategy of SCRI and MRS to meet end-user needs. The KTE strategy at SCRI is continually evolving in response to Policy and end-user needs.

The routes and mechanisms of KTE are extensive and are outlined in Fig. 2.

The extent of Industrial and Commercial interactions is given below:
- 75 active commercial customers
- >550 customers since 1997
- MRS Lipid Unit provides analytical services to over 50 active clients in the pharmaceutical, food, agricultural, marine and chemical industries

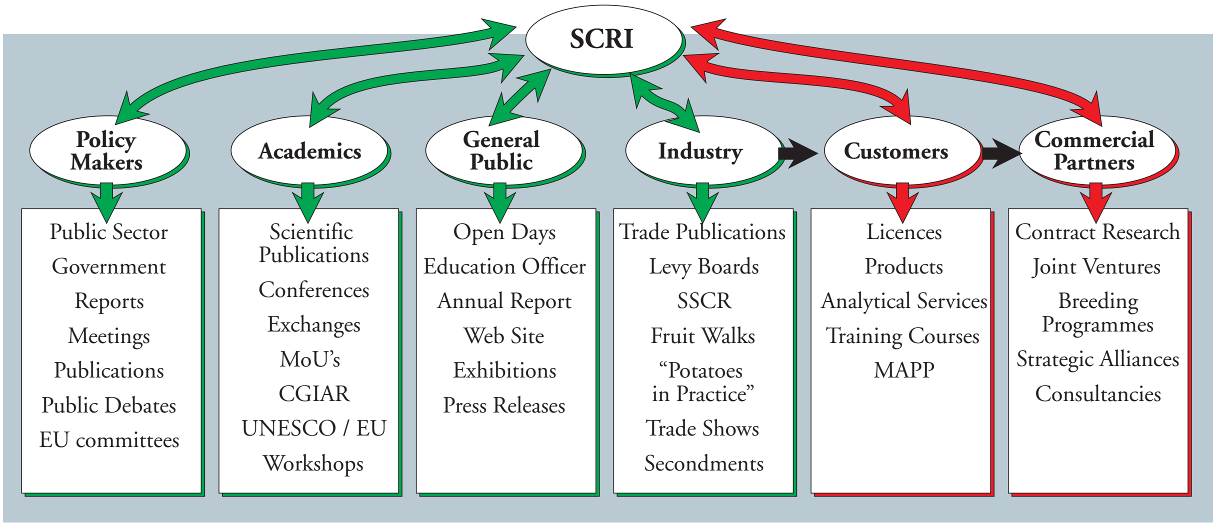


Figure 2 Knowledge transfer and exploitation. Commercial( ), Non-commercial( )

16 new companies visited SCRI in 2004

Over 450 licences

Acknowledgements MRS gratefully acknowledges the support of all SCRI staff, for their significant contribution to the success of the company. MRS would also like to thank its customers and sponsors for their continued support.

Mylnefield Trust and Mylnefield Holdings Ltd. (MHL) 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, such as Scottish Potato Technology Ltd, that MHL on behalf of the SCRI Group will hold equity.

The Trustees are a group of individuals, including several members of the MRS Board of Directors and the SCRI Governing Body. The Trust currently has funds of approximately £300K, achieved mainly through donations from MRS Ltd.

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:

An Incentive Fund to provide further support for scientists actively winning external contracts to pursue scientific research

Funds to support the establishment of an Education Officer at SCRI

A hardship fund for an overseas student

Start-up funding for the Product Innovation Centre

Early in 2004 the Mylnefield Trust invited SCRI scientists to apply for funding to support scientific research and its dissemination. A total of 6 proposals were supported and details of the awards are given below:

The Trustees hope that this scheme will become an annual event.

Name	Title	Value
Gordon Simpson	Rapid Mapping of Novel *Arabidopsis* Flowering Time Mutants	£1,019
Leighton Pritchard, Ian Toth & Paul Birch	Extension of the *Erwinia* Genome Sequence Web site (Eca WEB) by the Development of a Novel Genome-Viewing Software Package (GenomeDiagram)	£5,200
David Marshall, Linda Cardle & Paul Shaw	Development and Curation of Domain Specific Databases for Plant snoRNA, Protein Localisation and Nucleolar Proteins	£2,000
Sharon Neilson	DNA Workshops	£2,990
Sharon Neilson	The Living Field Project	£7,500
Hugh Barker, Bruce Marshall and Alison Dolan	Development of an Interactive Web Tool for Providing Information from the Soft Fruit Pathogen Testing Programme	£2,640

Scottish Society for Crop Research

W.H. Macfarlane Smith

Registered Office:- c/o Scottish Crop Research Institute, Invergowrie, Dundee, DD2 5DA

Membership Numbers:-236

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:-

- by organizing field walks and meetings for the exchange of information
- by financing science based publications for the benefit of the membership
- through the formation of crop-based sub-committees which maintain contact with members on specialized topics
- by funding research at SCRI which is either 'pump-priming' to initiate new research or work for minority interests that the large funding bodies would not support

Fruit walk 2003

The Society continues to support research work on wheat mixtures and has just agreed support for an extension of work on a soft fruit pathogen database. Ongoing support is being provided for the consortium producing new varieties of raspberry and will continue until 2009.

The Annual General Meeting was held on 9^{th} July 2003 after which a presentation was given by Professor Wayne Powell, Deputy Director of SCRI, about the creation of a Product Innovation Centre for potatoes, soft fruit and grains at the Institute.

The Soft Fruit Walk was held on 18^{th} July 2003, and again attracted a lot of interest from growers and processors who were keen to see the latest advanced selections of raspberries, strawberries, blackcurrants and other soft fruits.

Potatoes in Practice

'Potatoes in Practice', the potato event supported by the Society, the British Potato Council, the Scottish Agricultural College, the Scottish Agricultural Science Agency and the Institute was again held in August. The event was well attended by over 200 people, most of whom were advisers with a particular interest in SCRI's work on potato blight and the early results of the blight survey project.

The Crop Sub-Committees held several meetings during the year to exchange information and to prioritize proposed research for approval and funding by the Committee of Management.

The decline in Society membership has continued but is now slowing. It is anticipated that membership will rise during the coming year. As a means of boosting membership, additional activities are being planned and life membership at £100 will be available from 2005 onwards.

The Committee of Management is keen to encourage growers and processors to join the Society and to participate not just in the various meetings but also in the management of the Society and its various Sub-Committees.

Plans are in place for the re-introduction of the Society Newsletter and it is hoped that the first of the new issues will appear in December 2004 or early January 2005.

The Society Honorary Secretary, Mr Ian Kelly, has resigned and been succeeded by Dr Bill Macfarlane Smith, a former member of staff and now Honorary Research Fellow of the Institute.

Health & Safety

M. De,Maine

Heath and safety training carried out this year included training in the use of ladders for the maintenance department and glasshouse group. Use of ladders is kept to an absolute minimum on the Institute but training in checks of portable access equipment and precautions to take are essential if use of a ladder is unavoidable. Training in fire safety and use of laminar flow cabinets continued as new staff start work. This training has been found to be very beneficial in reducing fire hazards on the Institute.

Emergency Breathing Apparatus team practice anti-spillage drills.

An asbestos survey was carried out by a licensed contractor. The locations of asbestos-containing materials (ACMs) were recorded. Most of the asbestos present was white asbestos but there was a small amount of brown. Some material, including all the brown asbestos, was identified as requiring extraction and this has been carried out. Extraction by licensed contractor took place at week-ends to avoid disrupting scientific work. Following extraction the air was cleaned of any dust, tested and certified as safe by another, independent, specialist contractor before the rooms affected were re-commissioned. The remaining ACMs are to be labelled and inspected regularly for damage.

A new road traffic system has been introduced on advice from a traffic consultant. This involves restricting traffic to one-way only on certain roads on the site and is designed to avoid potential accidents between vehicles and pedestrians.

A stress survey was carried out by means of a work analysis questionnaire, devised by the Health Education Board Scotland (HEBS), sent to all staff. Analysis of the results indicated there were no major problems but further work will be carried out to determine whether further training for managers, in stress awareness for example, should be introduced. The Institute has appointed harassment contacts and developed links with the University of Dundee's counselling service. Any SCRI member of staff can arrange to see a counsellor at Institute expense.

SCRI has signed up for the Scotland's Health at Work (SHAW) Bronze Award under which the Institute undertakes to encourage all aspects of healthy working. There have been poster displays on smoking, mental well-being and healthy eating. A number of activities such as five-a-side football, badminton and yoga have been organized by members of staff for lunch-time or after work.

Staff Association

J.K. Wilde

The objects of the SCRI Staff Association are;

To promote and encourage social and other activities in such a way as to bring together all grades of staff and in doing so further good relations between staff.

To operate any facility which will benefit a reasonable number of members, that number being at the discretion of the Executive Committee.

To raise money for the year's chosen charity.

The committee has worked diligently over the past year to uphold these objectives.

The larger events held during the year were the Christmas disco, lunch, and children's parties. In June the Association held the annual summer barbecue for staff and their families, with over 250 in attendance. Two popular quiz nights were held in the Fort Hotel in Broughty Ferry. Some other events that took place included windsurfing, dingy sailing, bowling/zapp zone night, hill walking, and a photo competition. Blood donor sessions are arranged several times a year and are coordinated to allow staff time to attend. Financial support was given to the production of an SCRI calendar, featuring images from in and around the Institute. This was offered for sale to staff and the public, with the proceeds donated to charity. The Association continues to support the golf, fishing, and football fraternities along with the Corporate Sports membership at Dundee University, also Yoga and Tai Chi sessions.

Member's benefits include entry into a monthly draw to win meal and cinema vouchers, use of National Trust corporate admission cards, Booker cash and carry card, discounted costs of the Christmas lunch in the staff restaurant, fresh cut trees and children's parties. A subscription to "Which" magazine is provided for the SCRI library. Members are offered 25% off the full cost of any event/activity when they participate. Subscription fees remain at £1.50 per month and membership, currently around 200, is open to anyone working at SCRI. Any individual who has maintained membership for 10 years or more and reaches normal retirement age receives a cheque for £50. The office bearers and committee are elected annually at the AGM where members are encouraged

to nominate both local and national charities to be beneficiaries of the funds raised throughout the year. The nominated charity for the year past was the Ninewells Dennis the Menace Cancer Campaign, which received a total of £1760.

The Staff Association remains an integral part of SCRI, as it contributes greatly to the corporate well being, while helping the Institute gain recognition with external organisations such as Investors in People, Work Life Balance, and most recently Scotland Health at Work Initiative (SHAW).

Publications

Publications for the year 2003 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.

Akhond, M.A.Y., Aziz, N. & Machray, G.C. 2003. Gene targeting using haploid higher plant tissue. *ISPMB Abstract,* Barcelona, June 2003. P

Allcroft, D.J. & Glasbey, C.A. 2003. A simulation-based method for model evaluation. *Statistical Modelling: An International Journal* **3**, 1-13. J

Allen, J.F. & Raven, J.A. 2003. Symbiosis, functional genomics and the evolution of cells. *Philosophical Transactions of the Royal Society of London B* **358**, 3-4. J

Ashman, M.R., Brookes, P.C. & Hallett, P.D. 2003. Are the links between soil aggregate size class, soil organic matter and respiration simply artefacts of the fractionation procedure? *Soil Biology and Biochemistry* **35**, 435-444. J

Avrova, A.O., Venter, E., Birch, P.R.J. & Whisson, S.C. 2003. Profiling and quantifying differential gene transcription in *Phytophthora infestans* prior to and during the early stages of potato infection. *Fungal Genetics and Biology* **40**, 4-14. J

Basu, A., Ghosh, M., Meyer, R., Powell, W., Basak, S.L. & Sen, S.K. 2003. Analysis of genetic diversity in cultivated jute determined by means of SSR markers and AFLP profiling. *Crop Science* **44**, 678-685. J

Baucher, M., Halpin, C., Petit-Conil, M. & Boerjan, W. 2003. Lignin: Genetic engineering and impact on pulping. *Critical Reviews in Biochemistry and Molecular Biology* **38**, 305-350. J

Baumgartner, P., Harper, K., Raemaekers, R.J.M., Durieux, A., Gatehouse, A.M.R., Davies, H.V. & Taylor, M.A. 2003. Large-scale production and purification of recombinant *Galanthus nivalis* agglutinin (GNA) expressed in the methylotrophic yeast *Pichia pastoris*. *Biotechnology Letters* **25**, 1281-1285. J

Beardall, J., Quigg, A. & Raven, J.A. 2003. Oxygen consumption: photorespiration and chlororespiration. In: Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). *Photosynthesis in Algae.* Kluwer, Dordrecht, 157-181. R

Begg, G.S., Young, M.W., Hawes, C., McNicol, J.W. & Squire, G.R. 2003. Modelling feral (volunteer) oilseed rape in relation to thresholds of impurity. *Proceedings of the 1st European Conference on the Co-existence of Genetically Modified Crops with Conventional Organic Crops,* Denmark, 13-14 November 2003, 169-171. P

Bengough, A.G. 2003. Root growth and function in relation to soil structure, composition and strength. In: de Kroon, H. & Visser, E.J.W. (eds). *Root Ecology.* Springer-Verlag, Berlin Heidelberg, 151-171. R

Bingham, I.J. & Bengough, A.G. 2003. Morphological plasticity of wheat and barley roots in response to spatial variation in soil strength. *Plant and Soil* **250**, 273-282. J

Birch, A.N.E., Gordon, S.C., Fenton, B., Malloch, G., Mitchell, C., Jones, A.T., Griffiths, D.W., Brennan, R.M., Graham, J. & Woodford, J.A.T. 2003. Developing a sustainable IPM system for high value *Rubus* crops (raspberry, blackberry) for Europe (Poster). *COST 836 Final Workshop,* Ancona, 9-11 October 2003. P

Birch, A.N.E., Gordon, S.C., Woodford, J.A.T., Griffiths, D.W., Robertson, G. & Mitchell, C. 2003. Raspberry beetle monitoring and enhanced trapping using plant-derived volatile compounds from host flowers (Poster). *I Symposium on Raspberry,* Cacak, Serbia and Montenegro, 28-30 October 2003. P

Birch, A.N.E., Jones, A.T., Malloch, G., Fenton, B. & Gordon, S.C. 2003. Resistance-breaking raspberry aphid biotypes: a challenge for plant breeding. *Integrated Protection of Fruit Crops (Soft Fruits),* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin* **26,** 51-54. P

Birch, P.R.J., Avrova, A.O., Armstrong, M., Venter, E., Taleb, N., Phillips, M.S., Gilroy, E. & Whisson, S.C. 2003. The potato-*Phytophthora infestans* interaction transcriptome. *Canadian Journal of Plant Pathology* **25**, 226-231. J

Blackwell, A., Stuart, A.E. & Estambale, B.A. 2003. The repellant and antifeedant activity of oil of *Myrica gale* against *Aedes aegypti* mosquitoes and its enhancement by the addition of salicyluric acid. *Proceedings of the Royal College of Physicians of Edinburgh* **33**, 209-214. J

Blok, V.C. 2003. Development of tools for managing nematode pests of potatoes at the Scottish Crop Research Institute. *International Plant Protection Congress,* Beijing, China, July 6-11, 2003. P

Blok, V.C. 2003. Perspectives from molecular plant-nematode interactions. (abstract). *Quarantine Root-Knot Nematodes in Europe,* Wageningen, The Netherlands, 9-10 October 2003. P

Blok, V.C., Armstrong, M., Phillips, M.S., Paterson, A., Young, V., Avrova, A.O. & Birch, P.R.J. 2003. Expression of a WRKY-like transcription factor in potato roots in response to infection by potato cyst nematodes (PCN) (Abstract). *British Society of Plant Pathology.* P

Booth, A., Russell, J.R., Thomas, W.T.B. & Powell, W. 2003. Rapid identification of barley yellow mosaic virus resistance in cultivars using Pyrosequencing™ technology. *Pyrosequencing.* O

Bos, J.I., Torto, T.A., Ochwo, M., Armstrong, M., Whisson, S.C., Birch, P.R.J. & Kamoun, S. 2003. Intraspecific comparative genomics to identify avirulence genes from *Phytophthora*. *New Phytologist* **159**, 63-73. J

Boswell, G.P., Jacobs, H., Davidson, F.A., Gadd, G.M. & Ritz, K. 2003. Growth and function of fungal mycelia in heterogeneous environments. *Bulletin of Mathematical Biology* **65**, 447-477. J

Boswell, G.P., Jacobs, H., Ritz, K., Gadd, G.M. & Davidson, F.A. 2003. A mathematical approach to studying fungal mycelia. *Mycologist* **17**, 165-171. J

Boutsika, K., Phillips, M.S., MacFarlane, S.A., Brown, D.J.F., Blok, V.C. & Holeva, R. 2002. Molecular diagnostics of trichodorid nematodes and their associated *Tobacco rattle virus* (TRV). *Plant Pathology* **53**, 110-116. J

Bradshaw, J.E., Bryan, G.J., Castelli, L., Dale, M.F.B., Phillips, M.S. & Ramsay, G. 2003. Progress in developing new resistance to PCN. *Crop Protection in Northern Britain 2004,* Dundee, 24-25 February 2004. P

Bradshaw, J.E., Dale, M.F.B. & Mackay, G.R. 2003. Use of mid-parent values and progeny tests to increase the efficiency of potato breeding for combined processing quality and disease resistance. *Theoretical and Applied Genetics* **107**, 36-42. J

Brandizzi, F., Hanton, S., Pinto da Silva, L., Boevink, P., Evans, D., Oparka, K.J., Denecke, J. & Hawes, C. 2003. ER quality control can lead to retrograde transport from the ER lumen to the cytosol and the nucleoplasm in plants. *Plant Journal* **34**, 269-281. J

Brendel, O., Handley, L.L. & Griffiths, H. 2002. Differences in $\delta^{13}C$ and diameter growth among remnant Scots pine populations in Scotland. *Tree Physiology* **22**, 983-992. J

Brendel, O., Handley, L.L. & Griffiths, H. 2003. The δ^{13} C of Scots pine (*Pinus sylvestris* L.) needles: Spatial and temporal variations. *Annals of Forest Science* **60**, 97-104. J

Brennan, R.M. & Gordon, S.L. 2003. Future perspectives in blackcurrant breeding. *Conference Proceedings for Rubus-Ribes Symposium, Acta Horticulturae* **585**, 39-46. P

Brennan, R.M., Hunter, E.A. & Muir, D.D. 2003. Relative effects of cultivar, heat-treatment and sucrose content on the sensory properties of blackcurrant juice. *Food Research International* **36**, 1015-1020. J

Brewer, M.J. 2003. Discretisation for Inference on Bayesian Mixture Models. *Statistics and Computing* **13**, 209-219. J

Brewer, M.J., Elston, D.A. & Nolan, A.J. 2003. Spatial mixture models for ordinal responses: grazing impacts in Scotland, UK. *Proceedings of the 18th International Workshop on Statistical Modelling,* Leuven, Belgium. P

Brooks, D.R., Bohan, D.A., Champion, G.T., Hawes, C., Heard, M.S., Haughton, A.J., Birchall, C., Clark, S.J., Dewar, A.M., Firbank, L.G., Perry, J.N., Rothery, P., Scott, R.J., Skellern, M., Woiwod, I.P., Baker, P., Bell, D., Browne, E., Fairfax, C.M., Garner, B., Haylock, L., Horne, S., Hulmes, S., Mason, N., Nuttal, P., Randle, Z., Sands, R., Singer, E. & Walker, J. 2003. Invertebrate responses to the management of genetically modified herbicide-tolerant and conventional spring crops. I. Soil surface active invertebrates. *Philosophical Transactions of the Royal Society of London B* **358**, 1847-1862. J

Brown, D.J.F., Neilson, R. & Karanastasi, E. 2003. Virus-vector and non-vector longidorids and trichodorids - a current prospective (abstract). *16th Symposium of the Nematological Society of Southern Africa,* South Africa, 30 June to 4 July 2003. P

Brown, J.W.S., Echeverria, M., Qu, L.-H., Lowe, T.M., Bachellerie, J.-P., Hüttenhofer, A., Kastenmayer, J.P., Green, P.J., Shaw, P. & Marshall, D.F. 2003. Plant snoRNA database. *Nucleic Acids Research* **31**, 432-435. J

Bruce, A., Stewart, D.D., Verrall, S.R. & Wheatley, R.E. 2003. Effects of volatiles from bacteria and yeast on the growth and pigmentation of sapstain fungi. *International Biodeterioration and Degradation* **51**, 101-108. J

Brunt, A.A. & Mayo, M.A. 2003. Plant Virus Taxonomy 2003. *Proceedings of the 8th International Conference of Plant Pathology (abstract),* Christchurch, New Zealand, 2-7 February, 2003. P

Bryan, G.J. 2003. Genomics and molecular breeding for crop plant improvement. *The BCPC International Congress - Crop Science & Technology 2003,* SECC, Glasgow, 3rd - 5th November 2003. P

Burford, E.P., Fomina, M. & Gadd, G.M. 2003. Fungal involvement in bioweathering and biotransformation of rocks and minerals. *Mineralogical Magazine* **67**, 1127-1155. J

Burford, E.P., Kierans, M. & Gadd, G.M. 2003. Geomycology: fungal growth in mineral substrata. *Mycologist* **17**, 98-107. J

Cacciola, S.O., Raudino, F., Cooke, D.E.L., Duncan, J.M. & Magnano di San Lio, G. 2003. *Phytophthora* species infecting typical plants of the Mediterranean region. In: McComb, J.A., Hardy, G.E.S. & Tommerup, I.C. (eds). *Phytophthora in Forests and Natural Ecosystems. Proceedings of the 2nd International IUFRO Working Party, 7.02.09 Meeting, Albany, W. Australia, 2001.* R

Campbell, C.D., Chapman, S.J., Cameron, C.N., Davidson, M.S. & Potts, J.M. 2003. A rapid microtiter plate method to measure carbon dioxide evolved from carbon substrate amendments so as to determine the physiological profiles of soil microbial communities by using whole soil. *Applied and Environmental Microbiology* **69**, 3593-3599. J

Canto, T. 2003. Enhancing transient expression of genes from agrobacterium-delivered T-DNAs in *Nicotiana benthamiana* in the absence of viral suppressors of gene silencing. *"Epigenetics" Annual Meeting of the German Genetics Society,* Kassel, September 26-29, 2003. P

Castelli, L., Ramsay, G., Bryan, G.J., Neilson, S.J. & Phillips, M.S. 2003. New sources of resistance to the potato cyst nematodes *Globodera pallida* and *G. rostochiensis* in the Commonwealth Potato Collection. *Euphytica* **129**, 377-386. J

Champion, G.T., May, M.J., Bennett, S., Brooks, D.R., Daniels, R.E., Firbank, L.G., Haughton, A.J., Hawes, C., Heard, M.S., Perry, J.N., Randle, Z., Rossall, M., Rothery, P., Skellern, M., Scott, R.J. & Squire, G.R. 2003. Crop management and agronomic context of the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Philosophical Transactions of the Royal Society of London B* **358**, 1801-1818. J

Chapman, S., Dawson, W.O., Donson, J., Kumagai, M.H., Lewandowski, D.J., Lindbo, J.A. & Shivprasad, S. 2003. Method of enhancing RNA or protein production using non-native 5' untranslated sequence in recombinant viral nucleic acids. *US Patent Application.* 09/008,186 CIP. T

Chen, Q., Brown, D.J.F., Curtis, R.H. & Jones, J.T. 2003. Development of the magnetic capture system for recovery of *Xiphinema americanum. Annals of Applied Biology* **143**, 283-289. J

Chen, Q., Curtis, R.H., Lamberti, F., Mones, M., Brown, D.J.F. & Jones, J.T. 2002. Using monoclonal antibodies to discover parasitism proteins from the virus-vector nematode *Xiphinema index*. *Fourth International Congress of Nematology. Programme and Abstracts,* June 8-13, 2002 Tenerife, Canary Islands, Spain. P

Chen, W.M., James, E.K., Prescott, A.R., Kierans, M. & Sprent, J.I. 2003. Nodulation of *Mimosa* spp. by the beta-proteobacterium *Ralstonia taiwanensis*. *Molecular Plant Microbe-Interactions* **16**, 1051-1061. J

Christie, W.W. 2003. 13-Phenyltridec-9-enoic and 15-phenylpentadec-9-enoic acids in *Arum maculatum* seed oil. *European Journal of Lipid Science and Technology* **105**, 779-780. J

Christie, W.W. 2003. Analysis of conjugated linoleic acid - an overview. In: Sebedio, J.L., Christie, W.W. & Adlof, R.O. (eds). *Advances in Conjugated Linoleic Acid Research. Volume 2.* AOCS Press, Champaign, Illinois, 1-12. R

Christie, W.W. (ed). 2003. *Lipid Analysis. 3rd ed.* The Oily Press, Bridgewater, 416pp. R

Christie, W.W. 2003. Solid-phase extraction columns in the analysis of lipids. *Lipid Technology* **15,** 16-19. O

Christie, W.W. 2003. The biological activity of glycerophospholipids. *Lipid Technology* **15,** 105-108. O

Collins, H.M., Swanston, J.S., Rossnagel, B.G. & Logue, S.J. 2003. An investigation of the relative rates of protein and carbohydrate modification of a number of international malting varieties, grown in three countries. *9th International Barley Genetics Symposium,* Brno, Czech Republic, 20-26 June 2004. P

Comber, A.J., Birnie, R.V. & Hodgson, M.F.A. 2003. A retrospective analysis of land cover change using a polygon shape index. *Global Ecology and Biogeography* **12**, 207-215. J

Cooke, D.E.L., Lees, A.K. & Duncan, J.M. 2003. New tools for tracking late blight. *Crop Protection in Northern Britain 2004,* Dundee, 24-25 February 2004. P

Cooke, D.E.L., Williams, N.A. & Duncan, J.M. 2003. The reliability of rDNA internal transcribed spacer sequence analysis in *Phytophthora* identification and taxonomy. In: McComb, J.A., Hardy, G.E.S. & Tommerup, I.C. (eds). *Phytophthora in Forests and Natural Ecosystems. Proceedings of the 2nd International IUFRO Working Party 7.02.09 Meeting, Albany, W. Australia, 2001*, 159-166. R

Cooke, D.E.L., Young, V., Birch, P.R.J., Toth, R., Gourlay, F., Day, J.P., Carnegie, S. & Duncan, J.M. 2003. Phenotypic and genotypic diversity of *Phytophthora infestans* populations in Scotland (1995-1997). *Plant Pathology* **52**, 181-192. J

Cooke, D.E.L., Young, V. & Duncan, J.M. 2003. The validation and exploitation of a PCR-based diagnostic test for detecting *Phytophthora fragariae* in strawberry and raspberry (poster). *I Symposium on Raspberry,* Cacak, Serbia and Montenegro, 28-30 October 2003. P

Cooke, D.E.L., Young, V., Guy, D. & Duncan, J.M. 2003. Validation and exploitation of a PCR-based diagnostic for detecting *Phytophthora* in strawberry and raspberry (Poster). *COST 836 Final Workshop,* Ancona, 9-11 October 2003. P

Crawshaw, W.M. & Brocklehurst, S. 2003. An abortion epidemic in a dairy herd associated with horizontally transmitted *Neospora caninum* infection. *Veterinary Record* **152**, 201-206. J

Cross, J.V. & Gordon, S.C. 2003. Raspberry beetle and cane midge. *Ashford Fruit Conference,* Ashford, Kent. P

Cullen, D.W., Lees, A.K., Toth, I.K. & Duncan, J.M. 2002. Detection of *Colletotrichum coccodes* from soil and potato tubers by conventional and quantitative real-time PCR. *Plant Pathology* **51**, 281-292. J

Dale, M.F.B. & Bradshaw, J.E. 2003. Progress in improving processing attributes in potato. *Trends in Plant Science* **8**, 310-312. J

Dale, M.F.B. & Griffiths, D.W. 2003. Potatoes as a source of Vitamin C in our diets: germplasm and environmental effects. *EAPR, Conference on DSS and General Physiology,* Scottish Crop Research Institute, Dundee, March 2003. P

Dale, M.F.B., Griffiths, D.W. & Todd, D. 2003. Effects of genotype, environment and post-harvest storage on the total ascorbate content of potato (*Solanum tuberosum*) tubers. *Journal of Agricultural and Food Chemistry* **51**, 244-248. J

Daniell, T.J., Squires, J. & Nunan, N. 2003. Rhizoplane diversity of nitrate reductase in upland pasture. *FEMS Congress of European Microbiologists,* Llubijana, Slovenia, June 2003. P

Dawson, L.A., Grayston, S.J., Murray, P.J., Cook, R., Gange, A.C., Ross, J.M., Pratt, S.M., Duff, E.I. & Treonis, A. 2003. Influence of pasture management (nitrogen and lime addition and insecticide treatment) on soil organisms and pasture root system dynamics in the field. *Plant and Soil* **255**, 121-130. J

Dennis, P., Evans, D.M., Skartveit, J., Stephen, L., Pakeman, R.J., Pearce-Higgins, J., Redpath, S., Mayes, R.W., McCracken, D., Gordon, I.J., Grant, M., Elston, D.A., Kunaver, A., Quinn, S., Benton, T., Bryant, D. & Marquiss, M. 2003. Effects of grazing management on upland bird populations: disentangling habitat structure and arthropod food supply. *British Ecological Society Annual Meeting, 52,* Manchester Metropolitan University, Manchester. P

Di Matteo, A., Hancock, R.D., Ross, H.A., Frusciante, L. & Viola, R. 2003. Characterisation of *Chlorella pyrenoidosa* L-ascorbic acid accumulating mutants: Identification of an enhanced biosynthetic enzyme activity and cloning of the putative gene from *Arabidopsis thaliana*. (Poster). *Proceedings of SEB 2003*, Southampton. *Comparative Physiology and Biochemistry* **134**, S155. P

Dobson, G. 2003. Gas chromatography - mass spectrometry of conjugated linoleic acids and metabolites. In: Sebedio, J.L., Christie, W.W. & Adlof, R.O. (eds). *Advances in Conjugated Linoleic Acid Research, Volume 2.* AOCS Press, Champaign, Illinois, Chapter 2, 13-36. R

Douglas, A.E. & Raven, J.A. 2003. Genomes at the interface between bacteria and organelles. *Philosophical Transactions of the Royal Society of London B* **358**, 5-12. J

Douglas, S., Raven, J.A. & Larkum, A.W.D. 2003. The algae and their general characteristics. In: Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). *Photosynthesis in Algae.* Kluwer, Dordrecht, 1-10. R

Duncan, J.M. 2003. Diseases and pests of raspberry: prospects for integrated control. *Invited plenary paper, I Symposium on Raspberry,* Cacak, Serbia and Montenegro, 28-30 October 2003. P

Durban, M., Hackett, C.A., McNicol, J.W., Newton, A.C., Thomas, W.T.B. & Currie, L.D. 2003. The practical use of semiparametric models in field trials. *Journal of Agricultural, Biological and Environmental Statistics* **8**, 48-66. J

Elliott, M.J., Trudgill, D.L., McNicol, J.W. & Phillips, M.S. 2003. A Program to Investigate PCN Management Strategies. *EAPR, Third International Potato Modelling Conference,* Scottish Crop Research Institute, Dundee, March 2003. P

Ellis, C.J., Crittenden, P.D., Scrimgeour, C.M. & Ashcroft, C.J. 2003. The natural abundance of ^{15}N in mat-forming lichens. *Oecologia* **136**, 115-123. J

Elston, D.A., Duncan, A.J. & Ginane, C. 2003. Estimating the effect of positive and negative stimuli on diet selection by goats: an analysis of some repeated-measures compositional data. *International Biometric Society British Region Conference 2003,* University of Reading, UK. 36. P

Escobar, N.M., Haupt, S., Thow, G., Boevink, P., Chapman, S. & Oparka, K.J. 2003. High-throughput viral expression of cDNA-GFP fusions reveals novel subcellular addresses and identifies unique proteins that interact with plasmodesmata. *Plant Cell* **15**, 1507-1523. J

Fauquet, C.M., Bisaro, D.M., Briddon, R.W., Brown, J.K., Harrison, B.D., Rybicki, E.P., Stenger, D.C. & Stanley, J. 2003. Revision of taxonomic criteria for species demarcation in the family *Geminiviridae*, and an updated list of begomovirus species. *Archives of Virology* **148**, 405-421. J

Feeney, D., Daniell, T.J., Hallett, P.D., Ritz, K. & Young, I.M. 2003. Fungi as habitat engineers. *BES Soil Biodiversity Meeting,* Lancaster, UK, March 2003. P

Fenton, B., Malloch, G., Navajas, M., Hillier, J. & Birch, A.N.E. 2003. Clonal composition of the peach-potato aphid *Myzus persicae* (Homoptera: Aphididae) in France and Scotland. *Annals of Applied Biology* **142**, 255-267. J

Fernie, C.E. 2003. Conjugated linoleic acid. In: Caballero, B., Trugo, L. & Finglas, P. (eds). *Encyclopedia of Food Sciences and Nutrition.* Academic Press Ltd/Elsevier Science Ltd, London, 1581-1587. R

Filipe, J.A.N. & Rodgers, G.J. 2003. Exact solution of a generalized model for surface deposition. *Physical Review E* **68**, art. no. 027102. J

Firbank, L.G., Heard, M.S., Woiwod, I.P., Hawes, C., Haughton, A.J., Champion, G.T., Scott, R.J., Hill, M.O., Dewar, A.M., Squire, G.R., May, M.J., Brooks, D.R., Bohan, D.A., Daniels, R.E., Osborne, J.L., Roy, D.B., Black, H.I.J., Rothery, P. & Perry, J.N. 2003. An introduction to the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology* **40**, 2-16. J

Flavell, A.J., Bolshakov, V.N., Booth, A., Jing, R-C., Russell, J.R., Ellis, T.H.N. & Isaac, P. 2003. A microarray-based high throughput molecular marker genotyping method: the tagged microarray marker (TAM) approach. *Nucleic Acids Research* **31**, e115. J

Fomina, M., Ritz, K. & Gadd, G.M. 2003. Nutritional influence on the ability of fungal mycelia to penetrate toxic metal-containing domains. *Mycological Research* **17**, 861-871. J

Fonseca, S., Wilson, I., Maltin, C.A. & Horgan, G.W. 2003. Slow Fibre Cluster Pattern in Pig Longissimus Muscle: Implications for Myogenesis. *Journal of Animal Science* **81**, 973-983. J

Forster, B.P., Taeb, M. & Koebner, R.M.D. 2003. The genetic control of salt tolerance in the *Triticeae*: the effect of *Vrn* and *Ppd* genes. In: Naqvi, S.S.M. (ed.). *New Genetical Approaches to Crop Improvement.* Atomic Energy Research Centre, Tando Jam 70060, Pakistan, 497-512. R

Gadd, G.M., Burford, E.P. & Fomina, M. 2003. Biogeochemical activities of microorganisms in mineral transformations: consequences for metal and nutrient mobility. *Journal of Microbiology and Biotechnology* **13**, 323-331. J

Gadd, G.M. 2003. Toxic metal contamination treatment with microbes. In: Sasek, V., Glaser, J.A. & Baveye, P. (eds). *The Utilization of Bioremediation to Reduce Soil contamination: Problems and Solutions.* Kluwer Academic Publishers, Dordrecht, 75-94. R

Gambling, L., Dunford, S., Wallace, D.I., Zuur, G., Solanky, N., Srai, K.S. & McArdle, H.J. 2003. Iron deficiency during pregnancy affects post-natal blood pressure in the rat. *Journal of Physiology* **552**, 603-610. J

Geddes, A., Gimona, A. & Elston, D.A. 2003. Estimating local variations in land use statistics. *International Journal of Geographic Information Science* **17**, 299-319. J

Gillespie, T. 2003. Out-of-season raspberry production at SCRI: a brief overview of the long-cane system. *HDC Raspberry Trial Fruit Walk, July 2000.* T

Giordano, M., Norici, A., Forssen, M., Eriksson, M. & Raven, J.A. 2003. An anaplerotic role for mitochondrial carbonic anhydrase in *Chlamydomonas reinhardtii. Plant Physiology* **132**, 2126-2134. J

Goodman, B.A. & Cheshire, M.V. 2002. Characterisation by Mössbauer spectroscopy of the forms of iron in sulfide-rich fulvic acid solutions. *Hyperfine Interactions* **142**, 549-558. J

Goodman, B.A., Muckenschnabel, I., Lyon, G.D., Deighton, N., Stewart, D. & Williamson, B. 2003. Perturbation of redox processes in plant tissues as a result of attack by the necrotrophic pathogen, *Botrytis cinerea.* (Abstract). *Proceedings of the 36th Annual Meeting of the Electron Spin Resonance Group of the Royal Society of Chemistry,* University of Manchester, 10-11 April 2003. P

Goodman, B.A., Palivan, C.G., Palivan, H. & Tomas, S. 2003. Local structure is critical for superoxide dismutase activity in copper complexes: Relationship between EPR parameters, structure and activity in some sterically hindered copper(II) bis (hydrazono-triazine) complexes. *Applied Magnetic Resonance* **25**, 13-28. J

Goodman, B.A. & Reichenauer, T.G. 2003. Formation of paramagnetic products in leaves of wheat (*Triticum aestivum*) as a result of ozone-induced stress. *Journal of the Science of Food and Agriculture* **83**, 1248-1255. J

Gordon, S.C. 2003. Cooperative disease and pest control trials in cane and bush fruits (abstract). *Cost 836 Final Workshop (http://www.agr.unian.it/ricerca/prog_ric/cost836.htm),* Ancona, 9-11 October 2003. P

Gordon, S.C., Birch, A.N.E., Brennan, R.M. & Graham, J. 2003. Alternative control strategies for managing pests of cane and bush fruits in Europe (Abstract). *Advances in European Crop Protection,* John Innes Centre, Norwich, 19-20 May 2003. P

Gordon, S.C., Birch, A.N.E., Woodford, J.A.T. & Mitchell, C. 2003. Managing pests of raspberry using IPM techniques - European Experience (abstract). *I Symposium on Raspberry,* Cacak, Serbia and Montenegro, 28-30 October 2003. P

Gordon, S.C. & Williamson, B. 2003. Review of current knowledge of disease and pest control trials in cane and bush fruits in Europe. *COST Action 836 Final Workshop,* Ancona, Italy, 9-11 October 2003. *Acta Horticulturae.* P

Gordon, S.C., Woodford, J.A.T., Grassi, A., Zini, M., Tuovinen, T., Lindqvist, I. & McNicol, J. 2003. Monitoring and importance of wingless weevils (*Otiorhynchus* spp.) in European red raspberry production. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin* **26(2)** 55. P

Graham, J., Hein, I., Russell, J.R., Woodhead, M., Gordon, S.C. & Smith, K. 2003. The use of genomics technologies in contemporary *Rubus* and *Ribes* breeding programmes. *Acta Horticulturae,* **649**, 319-322. P

Graham, J., Marshall, B. & Squire, G.R. 2003. Genetic differentiation over a spatial environmental gradient in wild *Rubus idaeus* populations. *New Phytologist* **157**, 667-675. J

Graham, J., Russell, J.R., Hein, I. & Powell, W. 2003. An integrated approach to mapping in *Rubus. Abstracts of the Annual Main Meeting of the Society for Experimental Biology,* **134/A (3/Suppl.)** 5143-5144. P

Graham, J., Squire, G.R. & Marshall, B. 2003. Spatially distributed genetic similarity in wild *Rubus idaeus* populations. *Molecular Ecology* **15**, 667-675. J

Griffiths, B.S., Neilson, R. & Bengough, A.G. 2003. Soil factors determined nematode community composition in a two year pot experiment. *Nematology* **5**, 889-897. J

Gunstone, F.D. 2003. Fatty acids (c) Gamma-linolenic acid. In: Caballero, B., Trugo, L. & Finglas, P. (eds). *Encyclopedia of Food Science and Nutrition (2nd edition).* Elsevier, Amsterdam, 2308-2311. R

Gunstone, F.D. 2003. Giants from the past - Thomas Percy Milditch 1886-1965. *INFORM* **14,** 302-303. O

Gunstone, F.D. 2003. Lipid chemistry - a personal view of some developments in the last sixty years. *Biochimica et Biophysica Acta* **1631**, 207-217. J

Gunstone, F.D. 2003. *Lipids for Functional Foods and Nutraceuticals.* Oily Press, Bridgwater, Somerset, 322pp. R

Gunstone, F.D. 2003. Market Focus. *Lipid Technology Newsletter* **9,** 18-19, 42-43. O

Gunstone, F.D. 2003. Market Report. *INFORM* **14,** 42-43, 72-73. O

Gunstone, F.D. 2003. Market Report. *Lipid Technology* **15,** 28, 48, 72, 86, 120, 144. O

Gunstone, F.D. 2003. Market Report. *Lipid Technology Newsletter* **9,** 20, 44, 68, 92, 116, 140. O

Gunstone, F.D. 2003. Research Highlights. *Lipid Technology* **15,** 19-22, 42-45, 67-70, 90-93, 114-117, 139-142. O

Gunstone, F.D. 2003. Soy (soya) bean oil. In: Caballero, B., Trugo, L. & Finglas, P. (eds) *Encyclopedia of Food Science and Nutrition. 2nd edition.* Elsevier, Amsterdam, 5375-5379. R

Gunstone, F.D., Yang, B. & Kallio, H. 2003. Oils containing oleic, palmitoleic, γ-linolenic, and stearidonic acids. In: Gunstone, F.D. (ed.). *Lipids for Functional Foods and Nutraceuticals.* Oily Press, Bridgwater, Somerset, 263-290. R

Guschina, I.A., Dobson, G. & Harwood, J.L. 2003. Lipid metabolism in cultured lichen photobionts with different phosphorus status. *Phytochemistry* **64**, 209-217. J

Hackett, C.A., Pande, B. & Bryan, G.J. 2003. Constructing linkage maps in autotetraploid species using simulated annealing. *Theoretical and Applied Genetics* **106**, 1107-1115. J

Haenni, A.-L., De Miranda, J.R., Falk, B.W., Goldbach, R., Mayo, M.A., Shirako, Y. & Toriyama, S. 2003. Genus Tenuivirus. *International Committee on Taxonomy and Classification of Viruses VIII ICTV Report* 1-8. O

Hallett, P.D. 2003. Roots: An ecological solution for slope stabilisation. *Soil Bioengineering* (Leaflet). O

Hallett, P.D., Gordon, D.C. & Bengough, A.G. 2003. Plant influence on rhizosphere hydraulic properties: direct measurements using a miniaturised infiltrometer. *New Phytologist* **157**, 597-603. J

Hallett, P.D., Griffiths, B.S., Kuan, H.L., Pitkin, Y., Barton, A.P., Watts, C.W. & Whitmore, A.P. 2003. Soil stability and resilience: the interplay between physical and biological recovery from stress. *EU PROLAND Workshop on Soil Physical Quality,* Pulawy, Poland, 2-4 October 2003. P

Hallett, P.D., Zhang, B. & Newson, T.A. 2003. Quantifying soil structural dynamics using fracture mechanics. *EU PROLAND Workshop on Soil Physical Quality,* Pulawy, Poland, 2-4 October 2003. P

Hallett, P.D., Zhang, B. & Peng, X.H. 2003. Subcritical water repellency: a fundamental mechanism in soil pore structure evolution. *2nd International Conference on Soil Quality Evolution Mechanisms,* Yingtan, China, 23-28 September 2003. P

Halpin, C. & Boerjan, W. 2003. Stacking transgenes in forest trees. *Trends in Plant Science* **8**, 363-365. J

Hancock, R.D., McRae, D., Jorna, C.S., Haupt, S. & Viola, R. 2003. Synthesis of L-ascorbic acid in plant phloem. *BMC Plant Biology* **3**, 7. J

Hancock, R.D., Tedone, L., McRae, D., Jorna, C.S. & Viola, R. 2003. Phloem L-ascorbic acid: synthesis or transport? *Proceedings of SEB 2003*, Southampton. *Comparative Physiology and Biochemistry* **134**, S149. P

Harris, K., Young, I.M., Gilligan, C., Otten, W. & Ritz, K. 2003. Effect of bulk density on the spatial organisation of the fungus *Rhizoctonia solani* in soil. *FEMS Microbiology Ecology* **44**, 45-56. J

Haughton, A.J., Champion, G.T., Hawes, C., Heard, M.S., Brooks, D.R., Bohan, D.A., Clark, S.J., Dewar, A.M., Firbank, L.G., Osborne, J.L., Perry, J.N., Rothery, P., Roy, D.B., Scott, R.J., Woiwod, I.P., Birchall, C., Skellern, M., Walker, J., Baker, P., Browne, E., Garner, B., Haylock, L., Horne, S., Mason, N. & Sands, R. 2003. Invertebrates responses to the management of genetically modified herbicide-tolerant and conventional spring crops. II. Within field epigeal and aerial arthropods. *Philosophical Transactions of the Royal Society of London B* **358**, 1863-1877. J

Hawes, C., Brooks, D.R., Bohan, D.A., Champion, G.T., Clark, S.J., Daniels, R.E., Dewar, A.M., Firbank, L.G., Haughton, A.J., Heard, M.S., Osborne, J.L., Parish, A.M., Perry, J.N., Rothery, P., Roy, D.B., Scott, R.J., Woiwod, I.P., Young, M.W. & Squire, G.R. 2003. Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of Genetically-Modified Herbicide-Tolerant crops. *Philosophical Transactions of the Royal Society of London B* **358**, 1899-1913. J

Haynes, S., Darby, A.C., Daniell, T.J., Webster, G., Van Veen, F., Godfray, H.C., Prosser, J.I. & Douglas, A.E. 2003. Diversity of bacteria associated with natural aphid populations. *Applied and Environmental Microbiology* **69**, 7216-7223. J

Heard, M.S., Hawes, C., Champion, G.T., Clark, S.J., Firbank, L.G., Haughton, A.J., Perry, J.N., Rothery, P., Scott, R.J., Squire, G.R. & Hill, M.O. 2003. Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops.1. Effects on abundance and diversity. *Philosophical Transactions of the Royal Society of London B* **358**, 1819-1832. J

Heard, M.S., Hawes, C., Champion, G.T., Clark, S.J., Firbank, L.G., Haughton, A.J., Perry, J.N., Rothery, P., Scott, R.J., Squire, G.R. & Hill, M.O. 2003. Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops II. Effects on individual species. *Philosophical Transactions of the Royal Society of London B* **358**, 1833-1846. J

Hilbeck, A. & Birch, A.N.E. 2003. The GMO Guidelines Project: Development of International Scientific Environmental Biosafety Guidelines for Transgenic Plants. In: Ehler, L.E., Sforza, R. & Mateille, T. (eds). *Genetics, Evolution and Biological Control*. CABI Publishing, Wallingford, Oxon, 207-218. R

Hillman, J.R. 2003. Biotechnology issues for the environment. *Biotech 2020: Crop Biotechnology in the World of 2020,* British Crop Protection Council, Elvetham Hall, Hartley Wintney, 24-25 February 2003. P

Horgan, G.W. & Stubbs, J. 2003. Predicting BMR in the obese is difficult. *International Journal of Obesity* **57**, 335-340. J

Husmeier, D. 2003. Detecting Recombination in 4-Taxa DNA Sequence Alignments with Bayesian Hidden Markov Models and Markov Chain Monte Carlo. *Molecular Biology and Evolution* **20**, 315-337. J

Husmeier, D. 2003. Reverse engineering of genetic networks with Bayesian networks. *Biochemical Society Transactions* **31**, 1516-1518. J

Husmeier, D. 2003. Sensitivity and specificity of inferring genetic regulatory interactions from microarray experiments with dynamic Bayesian networks. *Bioinformatics* **19**, 2271-2282. J

Hübschen, J., Oliveira, C.M.G., Auwerkerken, A., Barsi, L., Ferraz, L.C.C.B., Ipach, U., Lazarova, S., Liskova, M., Peneva, V., Robbins, R.T., Susulousky, A., Tzortzakakis, M., Ye, W., Zheng, J., Tasheen, Q., Fourie, H., Lamberti, F., Brown, D.J.F. & Neilson, R. 2003. Phylogenetic analysis of selected longidoridae based on 18s rDNA gene sequences. *16th Symposium of the Nematological Society of Southern Africa,* South Africa, 30 June to 4 July 2003. P

Isidore, E., van Os, H., Andrzejewski, S., Bakker, J., Barrena, I., Bryan, G.J., Caromel, B., van Eck, H., Ghareeb, B., De Jong, W., van Koert, P., Lefebvre, V., Milbourne, D., Ritter, E., Rouppe van der Voort, J., Rousselle-Bourgeois, F., van Vliet, J. & Waugh, R. 2003. Toward a marker-dense meiotic map of the potato genome: Lessons from Linkage Group I. *Genetics* **165**, 2107-2116. J

Ivandic, V., Thomas, W.T.B., Nevo, E., Zhang, Z. & Forster, B.P. 2003. Association of simple sequence repeats with quantitative trait variation including biotic and abiotic stress tolerance in *Hordeum spontaneum*. *Plant Molecular Biology* **122**, 300-304. J

Jarosz-Wilkolazka, A. & Gadd, G.M. 2003. Oxalate production by wood-rotting fungi growing in toxic metal-amended medium. *Chemosphere* **52**, 541-547. J

Jaufeerally-Fakim, Y., Autrey, J.C., Toth, I.K., Daniels, M. & Dookun, A. 2002. Amplification polymorphism among *Xanthomonas albilineans* strains, using a single oligonucleotide primer. *European Journal of Plant Pathology* **108**, 121-130. J

Jennings, N., Brennan, R.M. & Gordon, S.C. 2003. Commercial breeding for pest and disease resistance in cane and bush fruits. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC wprs Bulletin,* **26(2),** 67. P

Johns, P.M. & Boag, B. 2003. The spread and distribution of terrestrial planarians (Turbellaria: Tricladida: Geoplanidae) within New Zealand. *New Zealand Journal of Ecology* **27**, 201-206. J

Johnston, A.M., Scrimgeour, C.M., Kennedy, H.A. & Handley, L.L. 2003. Isolation of ammonium-N as 1-sulfonato-iso-indole for measurement of δ^{15}N. *Rapid Communications in Mass Spectrometry* **17**, 1099-1106. J

Johnstone, A.M., Faber, P., Gibney, E.R., Lobley, G.E., Elia, M., Horgan, G.W. & Stubbs, J. 2003. Effect of weight loss on psychometric and physiological characteristics. *12th European Congress on Obesity May 29-June 01, 2003,* Helsinki, Finland. P

Jones, A.T. 2001. Genus *Idaeovirus*. In: Tidona, A.A. & Durai, G. (eds). *The Springer Index of Viruses.* Springer Press, Berlin. R

Jones, A.T. 2003. Important virus diseases of cane fruit crops and their control. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin,* **26**, 169-175. P

Jones, A.T. & McGavin, W.J. 2003. Resurgence of virus problems in *Rubus* in the United Kingdom: possible effects on crop production and certification. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin,* **27**, 73-78. P

Jones, H.G., Archer, N., Rotenberg, E. & Casa, R. 2003. Radiation measurement for plant ecophysiology. *Journal of Experimental Botany* **54**, 1-11. J

Jones, J.T. 2002. Nematode sense organs. In: Lee, D.L. (ed.). *The Biology of Nematodes.* Taylor and Francis, London, 353-368. R

Jones, J.T., Furlanetto, L., Bakker, E., Banks, B., Blok, V.C., Chen, Q., Phillips, M.S. & Prior, A. 2003. Characterisation of a chorismate mutase from the potato cyst nematode *Globodera pallida. Molecular Plant Pathology* **4**, 43-50. J

Jung, T., Nechwatal, J., Cooke, D.E.L., Hartmann, G., Blaschke, M., Osswald, W., Duncan, J.M. & Delatour, C. 2003. *Phytophthora pseudosyringae* sp. nov., a new species causing root and collar rot of deciduous trees in Europe. *Mycological Research* **107**, 772-789. J

Kalinina, N., Roberts, I., Ryabov, E., Robinson, D.J., Oparka, K. & Taliansky, M. 2003. An umbraviral long-distance movement protein forms unique, protective ribonucleoprotein complexes. *XI Congress of International*

Society for Molecular Plant-Microbe Interactions, St Petersburg, Russia, 18-27 July 2003. P

Kim, S.-H., Ryabov, E., Brown, J.W.S. & Taliansky, M.E. 2003. The intracellular trafficking of the ORF3 protein of *Groundnut rosette umbravirus* (GRV). *Advances in Plant Virology,* AAB Conference. P

Krivtsov, V., Liddell, K., Bezginova, T., Salmond, R., Garside, A., Thompson, J., Palfreyman, J.W., Staines, H.J., Watling, R., Brendler, A. & Griffiths, B.S. 2003. Ecological interactions of heterotrophic flagellates, ciliates and naked amoebae in forest litter of the Dawyck Cryptogamic Sanctuary (Scotland, UK). *European Journal of Protistology* **39**, 183-198. J

Kulkarni, N.K., Kumar, P.L., Muniyappa, V., Jones, A.T. & Reddy, D.V.R. 2003. Studies on the natural and experimental host range of *Pigeonpea sterility mosaic virus. Journal of Mycology and Plant Pathology* **33**, 141-145. J

Kulkarni, N.K., Reddy, A.S., Kumar, P.L., Vijaynarasimha, J., Rangaswamy, K.T., Muniyappa, V., Reddy, L.J., Saxena, K.B., Jones, A.T. & Reddy, D.V.R. 2003. Broad-based resistance to *Pigeonpea sterility mosaic disease* in the accessions of *Cajanus scarabaeoides. Indian Journal of Plant Protection* **31**, 6-11. J

Kumar, P.L., Jones, A.T. & Reddy, D.V.R. 2003. A novel mite-transmitted virus with a divided RNA genome closely associated with *Pigeonpea sterility mosaic disease. Phytopathology* **93**, 81-91. J

Kustka, A., Sanudo-Wilhelmy, S., Carpenter, E.J., Capone, D.G. & Raven, J.A. 2003. A revised estimate of the Fe use efficiency of nitrogen fixation with special reference to the N_2 fixing cyanobacterium *Trichodesmium* (Cyanophyta). *Journal of Phycology* **39**, 12-25. J

Lacomme, C., Hrubikova, K. & Hein, I. 2003. Enhancement of virus induced gene silencing through viral-based production of inverted-repeats. *The Plant Journal* **34**, 543-553. J

Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). 2003. *Photosynthesis in Algae*. Kluwer, Dordrecht, 479pp. R

Laskin, A.I., Bennett, J.W. & Gadd, G.M. (eds). 2003. *Advances in Applied Microbiology. Volume 52.* Academic Press, New York, 412pp. R

Laskin, A.I., Bennett, J.W. & Gadd, G.M. (eds). 2003. *Advances in Applied Microbiology. Volume 53.* Academic Press, New York, 453pp. R

Lee, L., Liang, D., Palukaitis, P. & Gray, S.M. 2003. Biologically active regions of the *Potato leafroll virus* coat protein involved in particle assembly, virus movement and aphid transmission. *Abstracts American Society for Virology.* P

Legorburu, F.J., Font, I., Jordá, M.C., Keller, H., Schots, A., Harper, K., Liney, M., Serra, C., Pereira, L.C., Formica, L., Dell'Orco, M., Saldarelli, P., Minafra, A., Boscia, D., Gallitelli, D. & Mayo, M.A. 2003. Cloned antigens as no risk, standardized positive controls in ELISA. *Proceedings of the 8th International Congress of Plant Pathology (abstract),* Christchurch, New Zealand, 2-7 February 2003, 90. P

Leigh, F., Lea, V., Law, J., Wolters, P., Powell, W. & Donini, P. 2003. Assessment of EST and genomic microsatellite markers for variety discrimination and genetic diversity studies in wheat. *Euphytica* **133**, 359-366. J

Liu, J. & Marshall, D.F. 2003. Complex dynamics and system co-ordination in coupled enzymatic systems. *Dynamic Day's Conference,* Palma, Majorca, September 2003. P

Liu, J. & Marshall, D.F. 2003. Sufficient conditions for coordination of coupled non-linear biochemical systems: analysis of a simple, representative example. *Journal of Biological Systems* **11**, 275-291. J

Lopez, S., Bastida, J., Viladomat, F., Armand-Ugon, M., Este, J., Codina, C. & Stewart, D. 2003. Anti-human immunodeficiency virus type 1 (HIV-1) activity of lectins from *Narcissus* species. *Planta Medica* **69**, 109-112. J

Lund, B., Ortiz, R., Skovgaard, I., Waugh, R. & Andersen, S.B. 2003. Analysis of potential duplicates in barley gene bank collections using re-sampling of microsatellite data. *Theoretical and Applied Genetics* **106**, 1129-1138. J

Lyon, G.D., Newton, A.C., Marshall, B., Ball, L., Houston, A. & Natanson, L. 2003. Drastic: A database resource for the analysis of signal transduction in cells. *Proceedings of the 8th International Congress of Plant Pathology (abstract),* Christchurch, New Zealand, 2-7 February 2003. P

MacConnell, C.B., Murray, T.A., Burrows, C.L., Gordon, S.C., Birch, A.N.E. & Tanigoshi, L. 2003. Adopting Integrated Pest Management for the Raspberry Beetle *Byturus unicolor* Say (Coleoptera: Byturidae), for Washington State Red Raspberries. *IOBC Workshop on Integrated Soft Fruit Production,* Conthey, Switzerland. P

MacFarlane, S.A. 2003. Molecular determinants of the transmission of plant viruses by nematodes. *Molecular Plant Pathology* **4**, 211-215. J

Mansur, M., Mahrup, S., Kusnarta, V.C.D., Gill, J.S., McKenzie, B.M., Borrell, A.K. & Tisdall, J.M. 2003. Management of the short and unreliable water supply for crops on tropical-semi-arid Vertisols of West Nusa Tenggara, Eastern Indonesia. *International Conference of Cambodian Agricultural Research and Development Institute (CARDI),* Cambodia, 25-28 November 2003. P

Marshall, B. & Young, M.W. 2003. Automated on-farm assessment of tuber size distribution. *EAPR, Third International Potato Modelling Conference,* Scottish Crop Research Institute, Dundee, March 2003. P

Marshall, E.J.P., Brown, V.K., Boatman, N.D., Lutman, P.J., Squire, G.R. & Ward, L.K. 2003. The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**, 77-89. J

Martin, D.M.A., Hill, P., Barton, G.J. & Flavell, A.J. 2003. Visual representation of database search results: the RHIMS plot. *Bioinformatics* **19**, 1037-1038. J

Martino, E., Perotto, S., Parsons, R. & Gadd, G.M. 2003. Solubilization of insoluble inorganic zinc compounds by ericoid mycorrhizal fungi derived from heavy metal polluted sites. *Soil Biology and Biochemistry* **35**, 133-141. J

Matus, I., Corey, A., Filichkin, T., Hayes, P.M., Vales, M.I., Kling, J., Riera-Lizarazu, O., Sato, K., Powell, W. & Waugh, R. 2003. Development and characterisation of recombinant chromosome substitution lines (RCSLs) using *Hordeum vulgare* subsp. *spontaneum* as a source of donor alleles in a *Hordeum vulgare* subsp. *vulgare* background. *Genome* **46**, 1010-1023. J

Mayo, M.A. 2002. A summary of taxonomic changes recently approved by ICTV. *Archives of Virology* **147 (8)**, 1655-1656. J

Mayo, M.A. 2002. ICTV at the Paris ICV: Results of the plenary session and the binomial ballot. *Archives of Virology* **147**, 2254-2260. J

Mayo, M.A. 2003. Base-pairing in RNA virus replication and host plant defence. *Microbiology Today* **30**, 12-13. J

Mayo, M.A., Fauquet, C.M. & Maniloff, J. 2003. Taxonomic proposals on the web: new ICTV consultative procedures. *Archives of Virology* **148**, 609-611. J

Mesfin, A., Smith, K.P., Dill-Macky, R., Evans, C.K., Waugh, R., Gustus, C.D. & Muehlbauer, G.J. 2003. Quantitative trait loci for *Fusarium* head blight resistance in barley detected in a two-rowed by six-rowed population. *Crop Science* **43**, 307-318. J

Mirabolfathy, M., Alizadeh, A., Cooke, D.E.L., Duncan, J.M., Rahimian, H. & Ershad, D. 2003. Detection of the causal agents of pistachio gummosis by the polymerase chain reaction. *Iranian Journal of Plant Pathology* **38**, 29-34. J

Mitchell, C., Gordon, S.C., Birch, A.N.E. & Hubbard, S.F. 2003. Developing a 'lure and kill' system for raspberry beetle, *Byturus tomentosus*, in *Rubus* production. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin.* P

Mitchell, S., Wheatley, R.E., Squires, J. & Daniell, T.J. 2003. Spatial linkage between *NIRK* diversity and denitrification of activity in three arable fields. *FEMS Congress of European Microbiologists,* Llubijana, Slovenia, June 2003. P

Molina-Cano, J.-L., Simiand, J.P., Sopena, A., Perez-Vendrell, A.M., Dorsch, S., Rubiales, D., Swanston, J.S. & Jahoor, A. 2003. Mildew-resistant mutants induced in North American two- and six-rowed malting barley cultivars. *Theoretical and Applied Genetics* **107**, 1278-1287. J

Morris, W.L., Ducreux, L., Griffiths, D.W., Stewart, D., Lacomme, C., Davies, H.V. & Taylor, M.A. 2003. Characterisation and transgenic modification of carotenogenesis during tuber development and storage in potato. *Gordon Conference - Carotenoids 2004,* California, USA, 4-9 January 2004. P

Motta, E., Annesi, T., Pane, A., Cooke, D.E.L. & Cacciola, S.O. 2003. A new *Phytophthora* sp. infecting beech in Italy. *Plant Disease* **87**, 1005. J

Muckenschnabel, I., Lyon, G.D., Deighton, N., Goodman, B.A., Stewart, D. & Williamson, B. 2003. *Botrytis cinerea* perturbs redox processes as an attack strategy in plants. *Proceedings of the 8th International Congress of Plant Pathology (Abstract 15.76),* Christchurch, New Zealand, 2-7 February 2003. P

Muckenschnabel, I., Schulze Gronover, C., Deighton, N., Goodman, B.A., Lyon, G.D., Stewart, D. & Williamson, B. 2003. Oxidative effects in uninfected tissue in leaves of French bean (*Phaseolus vulgaris*) containing soft rots caused by *Botrytis cinera*. *Journal of the Science of Food and Agriculture* **83**, 507-514. J

Naylor, S.W., Low, J.C., Besser, T.E., Mahajan, A., Gunn, G.J., Pearce, M.C., McKendrick, I.J., Smith, D.G.E. & Gally, D.L. 2003. Lymphoid follicle-dense mucosa at the terminal rectum is the principal site of colonization of enterohemorrhagic *Escherichia coli* O157:H7 in the bovine host. *Infection and Immunity* **71(3)**, 1505-1512. J

Neilson, R., Karanastasi, E., Duarte, I.M., Almeida, M.T.M. & Brown, D.J.F. 2003. Trichodorids and 'spraing' disease (abstract). *16th Symposium of the Nematological Society of Southern Africa,* South Africa, 30 June-4 July 2003. P

Newton, A.C. 2002. Cereal Rusts and Powdery Mildews Bulletin (Foreward/Editorial/Introduction/ Information/ Contents). *Cereal Rusts and Powdery Mildews Bulletin* **30**, 1. O

Newton, A.C. & Guy, D.C. 2003. Genotype and phenotype deployment strategies to enhanced durability and efficacy of cultivar mixtures. *Proceedings of the Crop Protection in Northern Britain Conference 2004,* Dundee, 24-25 February 2004. P

Newton, A.C., Guy, D.C., Campbell, E. & Thomas, W.T.B. 2003. The effect of variable environment on powdery mildew resistance expression in barley. *Journal of Plant Diseases and Protection* **110**, 113-119. J

Newton, A.C., Lyon, G.D., Holmes, K., Smith, W. & Osnes, K. 2003. Agricultural composition and method for treatment of plants therewith. *European Patent No:* 28.07.00/NOA 200003865. T

Newton, A.C. & Swanston, J.S. 2003. Winter barley cultivar mixtures: why isn't everybody growing them? *9th International Barley Genetics Symposium,* Brno, Czech Republic, 20-26 June 2004. P

Newton, A.C., Swanston, J.S., Begg, G.S., McNicol, J.W. & Hoad, S. 2003. Barley cultivar mixtures in theory and practice. *Proceedings of the 8th International Congress of Plant Pathology (abstract),* Christchurch, New Zealand, 2-7 February 2003. P

Newton, A.C., Swanston, J.S. & Guy, D.C. 2003. Enhanced durability and utility of genes for resistance by deployment in cultivar mixtures. *XI Congress of International Society for Molecular Plant-Microbe Interactions,* St Petersburg, Russia, 18-27 July 2003. P

Nikolova-Damyanova, B., Dobson, G., Momchilova, S. & Christie, W.W. 2003. Cyclohexanediol fatty acid diesters as model compounds for mechanistic studies in silver ion high performance liquid chromatography. *Journal of Liquid Chromatography and Related Technologies* **26**, 1905-1912. J

Nunan, N., Wu, K., Young, I.M., Crawford, J.W. & Ritz, K. 2003. Spatial distribution of bacterial communities and their relationships with the micro-architecture of soil. *FEMS Microbiology Ecology* **44**, 203-215. J

Oliveira, C.M.G., Hübschen, J., Brown, D.J.F., Monteiro, A.R., Ferraz, L.C.C.B., Wright, F. & Neilson, R. 2003. Taxonomic relationships of selected *Xiphinema* and *Xiphidorus* nematode species from Brazil. *16th Symposium of the Nematological Society of Southern Africa,* South Africa, 30 June-4 July 2003. P

Palfreyman, J.W., Gartland, J.S., Sturrock, C.J., Lester, D., White, N.A., Low, G.A., Bech-Andersen, J. & Cooke, D.E.L. 2003. The relationship between 'wild' and 'building' isolates of the dry rot fungus *Serpula lacrymans. FEMS Microbiology Letters* **228**, 281-286. J

Palukaitis, P. & Garcia-Arenal, F. 2003. Cucumoviruses. *Advances in Virus Research* **62**, 241-323. J

Palukaitis, P., Kim, S.-H., Taliansky, M.E., Andreev, I., Fitzgerald, A.G., Kalinina, N.O. & Ryabov, E.V. 2003. Effects of deletion of the C-Terminal 33 amino acids of the *Cucmber mosaic virus* 3a protein on movement, RNA binding and inhibition of infection and translation. *American Society for Virology.* P

Palukaitis, P. & Shi, B.-J. 2003. Rcombination between cucumoviruses: The 2B gene determines the nature of the 3' terminal sequence. *Abstracts for EMBO Meeting,* May 2003. P

Peng, X.H., Zhang, B., Qiguo, Z., Hallett, P.D. & Horn, R. 2003. Influence of types of restorative vegetation influences on the wetting properties of degraded clayey Ultisol in subtropical China. *Geoderma* **115**, 313-324. J

Perera, L., Russell, J.R., Provan, J. & Powell, W. 2001. Levels and distribution of genetic diversity of coconut (*Cocos nucifera* L., var. *Typica* form *typica*) from Sri Lanka assessed by microsatellite markers. *Euphytica* **122(2)**, 381-389. J

Perera, L., Russell, J.R., Provan, J. & Powell, W. 2003. Studying genetic relationships among coconut varieties/populations using microsatellite markers. *Euphytica* **132**, 121-128. J

Perry, J.N., Rothery, P., Clark, S.J., Heard, M.S. & Hawes, C. 2003. Design, analysis and power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology* **40**, 17-31. J

Pirker, K.F., Reichenauer, T.G., Pascual, E.C., Kiefer, S., Soja, G. & Goodman, B.A. 2003. Steady state levels of free radicals in tomato fruit exposed to drought and ozone stress in a field experiment. *Plant Physiology and Biochemistry* **41**, 921-927. J

Potts, J.M. 2003. Basic concepts. In: Jolliffe, I.T. & Stephenson, D.B. (eds). *Forecast Verification: A Practitioner's Guide in Atmospheric Science.* Wiley, Chichester. R

Potts, J.M., Hirst, D.J., Miller, J.D., Edwards, A.C. & Elston, D.A. 2003. Comparison of trends in stream water quality. *Hydrological Processes* **17**, 2449-2462. J

Ramos, M.L.G., Parsons, R., Sprent, J.I. & James, E.K. 2003. Effect of water stress on nitrogen fixation and nodule structure of common bean. *Pesquisa Agropecuaria Brasileira* **38**, 339-347. J

Ramsay, G., Squire, G.R., Thompson, C.E., Cullen, D., Anderson, J.N. & Gordon, S.C. 2003. Understanding and predicting landscape-scale gene flow in oilseed rape. *Proceedings of the 1st European Conference on the Co-existence of Genetically Modified Crops with conventional Organic Crops,* Denmark, 13-14 November 2003, pp.102-104. P

Rao, S.J., Iason, G.R., Hulbert, I.A.R., Elston, D.A. & Racey, P.A. 2003. The effect of sapling density, heather height and season on browsing by mountain hares on birch. *Journal of Applied Ecology* **40**, 626-638. J

Raven, J.A. 2003. Biochemistry and physiology of photosynthesis. In: Norton, T.A. (ed.). *Out of the Past.* British Phycological Society, London, 19-29. R

Raven, J.A. 2003. Can plants rely on nitrate? *Trends in Plant Science* **8**, 314-315. J

Raven, J.A. 2003. Carboxysomes and peptidoglycan walls of cyanelles: possible physiological functions. *European Journal of Phycology* **38**, 47-53. J

Raven, J.A. 2003. Cycling silicon – the role of accumulation in plants. *New Phytologist* **158**, 419-421. J

Raven, J.A. 2003. Inorganic carbon concentrating mechanisms in relation to the biology of algae. *Photosynthesis Research* **77**, 151-171. J

Raven, J.A. 2003. Long-distance transport in non-vascular plants. *Plant Cell and Environment* **26**, 73-85. J

Raven, J.A. & Allen, J.F. 2003. Genomics and chloroplast evolution: what did the cyanobacteria ever do for plants? *Genome Biology* **4**, 209(1)-209(5). J

Raven, J.A. & Beardall, J. 2003. Carbohydrate metabolism and respiration in algae. In: Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). *Photosynthesis in Algae.* Kluwer, Dordrecht, 205-224. R

Raven, J.A. & Beardall, J. 2003. Carbon acquisition mechanisms in algae: carbon dioxide diffusion and carbon dioxide concentrating mechanisms. In: Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). *Photosynthesis in Algae.* Kluwer, Dordrecht, 225-244. R

Raven, J.A. & Geider, R.D. 2003. Adaptation, acclimation and regulation of photosynthesis in algae. In: Larkum, A.W.D., Douglas, S.E. & Raven, J.A. (eds). *Photosynthesis in Algae.* Kluwer, Dordrecht, 385-412. R

Raven, J.A., Handley, L.L. & Andrews, M. 2002. Optimising carbon-nitrogen budgets: perspectives for crop improvement. In: Foyer, C.H. & Noctor, G. (eds). *Photosynthetic Nitrogen Assimilation and Associated Carbon Metabolism.* Kluwer Academic Press, Dordrecht. R

Raven, J.A., Johnston, A.M., Kübler, J.E.K.R., McInroy, S.G., Handley, L.L., Scrimgeour, C.M., Walker, D.I., Beardall, J., Clayton, M.N., Chudek, J.A., Vanderklift, M., Fredricksen, S. & Dunton, K.H. 2002. Seaweeds in cold seas: evolution and carbon acquisition. *Annals of Botany* **90**, 525-536. J

Raven, J.A. & Skene, K.R. 2003. Chemistry of the oceans: the environment of early life. In: Rothschild, L. & Lister, A. (eds). *Evolution on Plant Earth: The Impact of the Physical Environment.* Academic Press, London, 55-64. R

Raven, J.A. & Taylor, R. 2003. Macroalgal growth in nutrient-enriched estuaries: a biogeochemical perpective. *Water, Air and Soil Pollution: Focus* **3**, 7-26. J

Read, D.B., Bengough, A.G., Gregory, P.J. & Scrimgeour, C.M. 2003. Plant roots release phospholipid surfactants that modify the physical and chemical properties of soil. *New Phytologist* **157**, 315-326. J

Rehmany, A.P., Grenville, L.J., Gunn, N.D., Allen, R.L., Paniwnyk, Z., Byrne, J., Whisson, S.C., Birch, P.R.J. & Beynon, J.L. 2003. A genetic interval and physical contig spanning the *Peronospora parasitica* (*At*) avirulence gene locus *ATR1Nd. Fungal Genetics and Biology* **38**, 33-42. J

Reichenauer, T.G. & Goodman, B.A. 2003. Free radicals in wheat flour change during storage in air and are influenced by the presence of ozone during the growing season. *Free Radical Research* **37**, 523-528. J

Ritchie, M.R., Morton, M.S., Deighton, N., Blake, A. & Cummings, J.H. 2003. Plasma and urinary phytoestrogens as biomarkers of intake: validated by duplicate diet analysis. *Food, Nutrition and Cancer Conference,* USA. (Poster). P

Ritchie, M.R., Morton, M.S., Deighton, N., Blake, A., Thompson, A.M., Cummings, J.H. & Steel, C.M. 2003. Derivation and validation of a biological marker for phytoestrogen intake. *Journal of Nutrition* **133(Suppl.)**, 3862S. J

Roberts, A.G. & Oparka, K.J. 2003. Plasmodesmata and the control of symplastic transport. *Plant Cell and Environment* **26**, 103-124. J

Roberts, I.M. 2002. Iso-butanol saturated water: a simple procedure for increasing staining intensity of resin sections for light and electron microscopy. *Journal of Microscopy* **207**, 97-107. J

Robinson, D.J. & Dale, M.F.B. 2003. Factors affecting the incidence of potato spraing disease caused by *Tobacco rattle virus*. *Proceedings, Crop Protection in Northern Britain 2004,* Dundee, 24-25 February 2004. P

Robinson, D.J., Dale, M.F.B., Bryan, G.J. & McLean, K. 2003. The inheritance of resistance to *Tobacco rattle virus* in potato. *AAB Advances in Plant Virology Conference,* (abstract). P

Rodger, S., Bengough, A.G., Griffiths, B.S., Stubbs, V. & Young, I.M. 2003. Does the presence of detached root border cells from *Zea mays* alter the activity of the pathogenic nematode *Meloidogyne incognita*? *Phytopathology* **93**, 1111-1114. J

Ross, H.A., Sungurtas, J., Ducreux, L., Swanston, J.S., Davies, H.V. & McDougall, G.J. 2003. Limit dextrinase in barley cultivars of differing malting quality: activity, inhibitors and limit dextrin profiles. *Journal of Cereal Science* **38**, 325-334. J

Rostoks, N., Cardle, L., Mudie, S., Ramsay, L., Hedley, P.E., Russell, J.R., Caldwell, D., Marshall, D.F. & Waugh, R. 2003. Single nucleotide polymorphism discovery in barley genes differentially expressed during abiotic stresses. *Plant and Aninmal Genome Conference (PAG) XII Proceedings,* San Diego, California, 10-12 January 2004. P

Rostoks, N., Mudie, S., Cardle, L., Marshall, D.F. & Waugh, R. 2003. Single nucleotide polymorphism mapping of the barley genes involved in abiotic stresses. *9th International Barley Genetics Symposium,* Brno, Czech Republic, 20-26 June 2004. P

Roy, D.B., Bohan, D.A., Haughton, A.J., Hill, M.O., Osborne, J.L., Clark, S.J., Perry, J.N., Rothery, P., Scott, R.J., Brooks, D.R., Champion, G.T., Hawes, C., Heard, M.S. & Firbank, L.G. 2003. Invertebrates and vegetation of field margins adjacent to crops subject to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Philosophical Transactions of the Royal Society of London B* **358**, 1879-1898. J

Russell, J.R., Booth, A., Fuller, J., Baum, M., Ceccarelli, S., Grando, S. & Powell, W. 2003. Patterns of polymorphism detected in the chloroplast and nuclear genomes of barley landraces sampled from Syria and Jordan. *Theoretical and Applied Genetics* **107**, 413-421. J

Schmidt, O., Dyckmans, J. & Scrimgeour, C.M. 2003. Isotopic labelling of earthworms: comments on the paper by Whalen and Janzen (2002). *Soil Biology and Biochemistry* **35**, 875-876. J

Scrimgeour, C.M. 2003. Book review: Food Lipids - Chemistry, Nutrition and Biotechnology, 2nd edition. Akoh, C.C. & Min, D.B. (eds). *European Journal of Lipid Science and Technology.* **105,** 381. O

Scrimgeour, C.M. & Robinson, D. 2003. Stable isotope analysis and applications. In: Smith, K.A. & Cresser, M.S. (eds.). *Soil and Environmental Analysis: Modern Instrumental Techniques.* Marcel Dekker Inc., New York. 381-431. R

Shepherd, T., Dobson, G., Marshall, R., Verrall, S.R., Conner, S., Griffiths, D.W., Stewart, D. & Davies, H.V. 2003. Analysis of metabolites from *Solanum* species using gas chromatography-(Time-of-Flight) mass spectrometry and automated data analysis. *16th International Mass Spectrometry Conference,* Edinburgh, 31 August-5 September 2003. (Poster) P

Shepherd, T. 2003. Wax pathways. In: Thomas, B., Murphy, D.J. & Murray, B.G. (eds). *Encyclopedia of Applied Plant Sciences.* Academic Press, 1204-1225. R

Shepherd, T., Dobson, G., Marshall, R., Verrall, S.R., Conner, S., Shepherd, L.V.T., McNicol, J.W., Deighton, N., Stewart, D. & Davies, H.V. 2003. Can metabolite profiling be used to identify unintended effects in transgenic tubers? *16th International Mass Spectrometry Conference,* Edinburgh, 31 August-5 September 2003. P

Shi, B.-J., Palukaitis, P. & Symons, R.H. 2003. Stable and unstable mutations in the 5' non-translated regions of *Tomato aspermy virus* RNAs 1 and 2 generated from infectious cDNA clones containing a cauliflower mosaic virus 35S promoter. *Virus Genes* **28**, 277-283. J

Soulsby, C., Petry, J., Brewer, M.J., Dunn, S.M., Ott, B. & Malcolm, I.A. 2003. Identifying and assessing uncertainty in hydrological pathways: a novel approach to end member mixing in a Scottish agricultural catchment. *Journal of Hydrology* **274**, 109-128. J

Sprent, J.I. 2003. Mutual sanctions. *Nature* **422**, 672-674. J

Squire, G.R., Brooks, D.R., Bohan, D.A., Champion, G.T., Daniels, R.E., Haughton, A.J., Hawes, C., Heard, M.S., Hill, M.O., May, M.J., Osborne, J.L., Perry, J.N., Roy, D.B., Woiwod, I.P. & Firbank, L.G. 2003. On the rationale and interpretation of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crop. *Philosophical Transactions of the Royal Society of London B* **358**, 1779-1799. J

Squirrell, J., Hollingsworth, P.M., Woodhead, M., Russell, J.R., Lowe, A., Gibby, M. & Powell, W. 2003. How much effort is required to isolate nuclear microsatellites from plants? *Molecular Ecology* **12**, 1339-1348. J

Stamati, K., Blackie, S., Brown, J.W.S. & Russell, J.R. 2003. A set of polymorphic SSR loci for sub-arctic willow (*S. lanata, S. lapponum* and *S. herbacea*). *Molecular Ecology Notes* **2**, 280-282. J

Steffenson, B.J., Thomas, W.T.B., Meyer, R.C. & Webster, R.K. 2003. Mapping of qunatitative trait loci conferring resistance to the rice blast pathogen *Pyricularia grisea* in barley. *ICPP,* 2002. P

Stewart, D. 2003. Berries - Nature's functional foods. *The Caledonian Grower - The Journal of the Royal Caledonian Horticultural Society* 43-46. O

Stewart, D. 2003. Effect of high O_2 and N_2 atmospheres on strawberry quality. *Acta Horticulturae,* **600**, 567-570. P

Stewart, D. 2003. Role of berries in human health. *COST 836 Workshop: Towards an Organisation of Integrated Research in Berries,* Ancona, Italy, 9-11 October 2003. P

Stewart, H.E., Bradshaw, J.E. & Pande, B. 2003. The effect of the presence of R-genes for resistance to late blight (*Phytophthora infestans* (Mont. de Bary) of potato (*Solanum tuberosum*) on the underlying level of field resistance. *Plant Pathology* **52**, 193-198. J

Swanston, J.S. & Newton, A.C. 2003. Do components of barley variety mixtures converge for malting quality attributes? *9th International Barley Genetics Symposium,* Brno, Czech Republic, 20-26 June 2004. P

Talamé, V., Sanguineti, M.C., Chiapparino, E., Bahri, H., Ben Salem, M., Ellis, R.P., Forster, B.P., Rhouma, S., Zoumarou, W. & Tuberosa, R. 2003. Advanced backcross QTL analysis for the identification of agronomically valuable alleles in wild barley (*Hordeum spontaneum*). *Abstracts of Conference "From the green revolution to the gene revolution",* P

Taliansky, M.E., Kim, S.-H., Ryabov, E.V., Robinson, D.J. & Brown, J.W.S. 2003. Involvement of the Nucleolus in Umbravirus Systemic Infection. *XI Congress of International Society for Molecular Plant-Microbe Interactions,* St Petersburg, Russia, 18-27 July 2003. P

Taliansky, M.E., Kim, S.-H., Ryabov, E.V. & Brown, J.W.S. 2003. Is the nucleolus a gateway to umbravirus systemic infection? *Abstract, EMBO workshop,* Keszthely, Hungary 2003. P

Taliansky, M.E., Mayo, M.A. & Barker, H. 2003. *Potato leafroll virus*: a classic pathogen shows some new tricks. *Molecular Plant Pathology* 4, 81-89. J

Taliansky, M.E., Mayo, M.A., Barker, H., Kim, S.-H. & Kalinina, N. 2003. Effect of biotic and abiotic factors on escape of *Potato leafroll virus* from amplicon-mediated RNA resistance. *XI Congress of International Society for Molecular Plant-Microbe Interactions,* St Petersburg, Russia, 18-27 July 2003. P

Taliansky, M.E., Robinson, D.J., Waterhouse, P.M., Murant, A.F., dr Zoeten, G.A., Falk, B.W. & GIBBS, M.J. 2003. Genus Umbravirus. *International Committee on Taxonomy and Classification of Viruses VIII ICTV Report* . O

Tedone, L., Hancock, R.D. & Viola, R. 2003. Long-distance transport of L-ascorbic acid in potato plants. *EAPR Physiology Meeting,* Dundee, March 2003. P

Teulat, B., Merah, O., Sirault, X., Borries, C., Waugh, R. & This, D. 2003. QTLs for grain carbon isotope discrimination in field-grown barley. *Theoretical and Applied Genetics* **106**, 118-126. J

Thangavelu, M., James, A., Bankier, A., Bryan, G.J., Dear, P. & Waugh, R. 2003. HAPPY mapping in a plant genome: reconstruction and analysis of a high-resolution physical map of a 1.9 Mbp region of *Arabidopsis thaliana* Chromosome 4. *Plant Biotechnology* **1**, 23-33. J

Thomas, W.T.B. 2003. Molecular Breeding for Barley Quality. *EUCARPIA Cereal Section Proceedings.* P

Thomas, W.T.B. 2003. Prospects for molecular breeding of barley. *Annals of Applied Biology* **142**, 1-12. J

Thomas, W.T.B. 2003. QTLs for resistance to leaf spotting in barley. *EUCARPIA Cereal Section Proceedings.* P

Titova, E.S., Chichkova, N.V., Kim, S.-H., Taliansky, M. & Vartapetyau, A.N. 2003. A Plant caspase-like protease activated in the course of the hypersensitive response. *XI Congress of International Society for Molecular Plant-Microbe Interactions,* St Petersburg, Russia, 18-27 July 2003. P

Toth, I.K. 2002. Better understanding of *Erwinia* for detection and reduced spread. *British Potato Council Technical Bulletin* **2002/13**. O

Trewavas, A.J. & Stewart, D. 2003. Paradoxical effects of chemicals in the diet on health. *Current Opinion in Plant Biology* **6**, 185-190. J

Trudgill, D.L., Elliott, M.J., Evans, K. & Phillips, M.S. 2003. The white potato cyst nematode (*Globodera pallida*) - a critical analysis of the threat in Britain. *Annals of Applied Biology* **143**, 73-80. J

Tsevegsuren, N., Fujimoto, K., Christie, W.W. & Endo, Y. 2003. The occurrence of a novel *cis*-3-octadecatrienoic (*all-cis*-octadeca-3,9,12-trienoic) acid in *Chrysanthemum (Tanacetum) zawadskii Herb* (Compositae) seed oil. *Lipids* **38**, 573-578. J

Tsonev, T., Velikova, V., Georgieva, K., Hyde, P.F. & Jones, H.G. 2003. Low temperature enhanced photoinhibition or photosynthetic down-regulation in french bean (*Phaseolus vulgaris* L.) plants. *Annals of Botany* **92**, 343-352. J

Turner, S.P., Horgan, G.W. & Edwards, S.A. 2003. Assessment of sub-grouping behaviour in pigs (*Sus scrofa*) housed at different group sizes. *Applied Animal Behaviour Science* **83**, 291-302. J

Urquhart, K.A. & McKendrick, I.J. 2003. A survey of permanent wound tracts in the carcasses of culled wild red deer in Scotland. *Veterinary Record* **152**, 497-501. J

van de Graaf, P., Lees, A.K., Cullen, D.W. & Duncan, J.M. 2003. Detection and quantification of *Spongospora subterranea* in soil, water and plant tissue samples using real-time PCR. *European Journal of Plant Pathology* **109**, 589-597. J

Verrall, S.R., Deighton, N., Marshall, R., Sungurtas, J., Shepherd, T., Shepherd, L.V.T., Dobson, G., McNicol, J.W. & Davies, H.V. 2003. Can metabolomics identify unintended effects in transgenic tubers? *2nd International Conference on Plant Metabolomics,* Potsdam, Germany, 25-28 April 2003. P

Viola, R. 2003. Handbook of Plant Growth: pH as the Master Variable. Z. Rengel. (ed.) Marcel Dekker Inc., New York (2002), pp. 446. (Book Review). *Experimental Agriculture* **39,** 109-110. O

von Post, R., von Post, L., Dayteg, C., Nilsson, M., Forster, B.P. & Tuvesson, S. 2003. A high throughput DNA extraction method for barley seed. *Euphytica* **130**, 355-360. J

Wei, W.X., Bilsborrow, P.E., Hooley, P., Fincham, D.A., Lombi, E. & Forster, B.P. 2003. Salinity induced differences in growth, ion distribution and partitioning in barley between the cultivar Maythorpe and its derived mutant Golden Promise. *Plant and Soil* **250**, 183-191. J

Werner, K., Friedt, W., Laubach, E., Waugh, R. & Ordon, F. 2003. Dissection of resistance to soil-borne yellow mosaic inducing viruses of barley (BaMMV, BaYMV, BaYMV-2) in a complex breeders cross by SSRs and simultaneous mapping of BaYMV/BaYMV-2 resistance of 'Chikurin Ibaraki 1'. *Theoretical and Applied Genetics* **106**, 1425-1432. J

Wheatley, R.E. 2003. A review of the possible effects of the cultivation of GM-crops on soil-ecosystem functioning. *International Joint Monte Verita Conference on "Biodiveristy Implications of Genetically Modified Plants",* 7-12 September 2003, Ascona, Switzerland. P

Wheatley, R.E., Caul, S., Crabb, D., Daniell, T.J., Griffiths, B.S. & Ritz, K. 2003. Microbial population dynamics related to temporal variations in nitrification in three arable fields. *European Journal of Soil Science* **54**, 707-714. J

Whisson, S.C., Basnayake, S., Maclean, D.J., Irwin, J.A.G. & Drenth, A. 2003. *Phytophthora sojae* avirulence genes *Avr4* and *Avr6* are located in a 24 kb, recombination-rich region of genomic DNA. *Fungal Genetics and Biology* **41**, 62-74. J

White, C., Dennis, J.S. & Gadd, G.M. 2003. A mathematical process model for cadmium precipitation by sulphate-reducing bacterial biofilms. *Biodegradation* **14**, 139-151. J

Windhovel, A., Hein, I., Dabrowa, R. & Stockhaus, J. 2001. Characterization of a novel class of plant homeodomain protein that bind to the C4 phosphoenolpyruvate carboxylase gene of *Flaveria trinervia. Plant Molecular Biology* **45**, 201-214. J

Wood, N.T. 2002. First plant circadian phase mutant identified (Review). *Trends in Plant Sciences* **7**, 482. O

Wood, N.T., MacLeod, M.R., Mayo, M.A., McGavin, W.J. & Jones, A.T. 2003. Some properties of the genome of *raspberry bushy dwarf virus. Proceedings of the 8th International Congress of Plant Pathology (abstract)* Christchurch, New Zealand, 2-7 February 2003, p.244. P

Woodford, J.A.T., Birch, A.N.E., Gordon, S.C., Griffiths, D.W., McNicol, J.W. & Robertson, G.W. 2003. Controlling raspberry beetle without insecticides. *Integrated Protection of Fruit Crops (Soft Fruits)* Dundee, 18-21 September 2001. *IOBC/wprs Bulletin* **26(2)** 87. P

Woodhead, M., Russell, J.R., Squirrell, J., Hollingsworth, P.M., Cardle, L., Ramsay, L., Gibby, M. & Powell, W. 2003. Development of EST-SSRs from the Alpine Lady Fern, *Athyrium distentifolium. Molecular Ecology Notes* **2**, 287-290. J

Woodhead, M., Russell, J.R., Squirrell, J., Hollingsworth, P.M., Gibby, M. & Powell, W. 2003. Assessing genetic diversity in *Athyrium distentifolium* using EST-SSRs (Poster). *Ecological Genetics Group Meeting.* P

Woodhead, M., Russell, J.R., Squirrell, J., Hollingsworth, P.M., Gibby, M. & Powell, W. 2003. Examining population differentiation in the circumarctic fern species *Athyrium distentifolium* using markers derived from gene transcripts. *Plant Speciation Conference (Poster).* P

Wright, K.M., Roberts, A.G., Martens, H.J., Sauer, N. & Oparka, K.J. 2003. Structural and functional vein maturation in developing tobacco leaves in relation to *AtSUC2* promoter activity. *Plant Physiology* **131**, 1555-1565. J

Yeates, G.W. & Boag, B. 2002. Post-embryonic growth of longidorid nematodes. *Nematology* **4**, 883-889. J

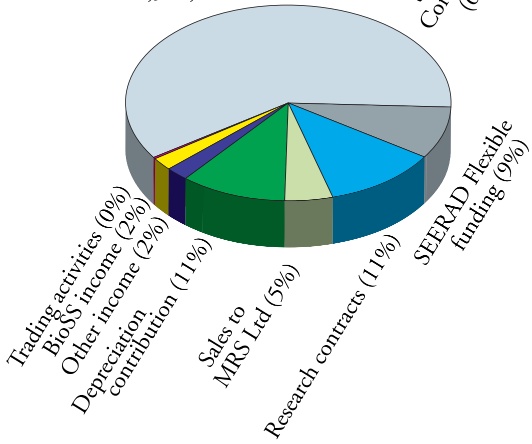
Yeates, G.W. & Boag, B. 2003. Growth and life histories in Nematoda, with particular reference to environmental factors. *Nematology* **5**, 653-664. J

Yu, D., Fan, B., MacFarlane, S.A. & Chen, Z. 2003. Analysis of the involvement of an inducible *Arabidopsis* RNA-dependent RNA polymerase in antiviral defence. *Molecular Plant Microbe-Interactions* **16**, 206-216. J

Summary of the Accounts

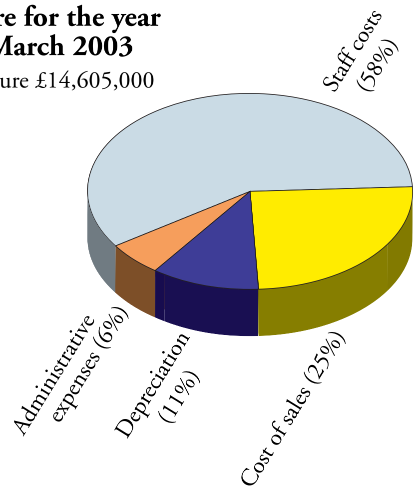
Income for the year ended 31 March 2003

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

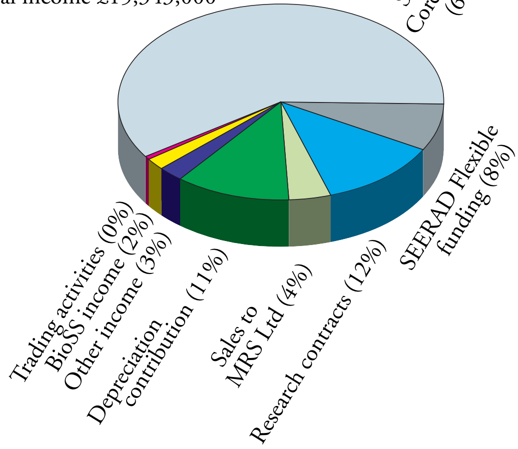
Fixed assets	94 %
Stocks	0 %
Debtors	6 %

Liabilities

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

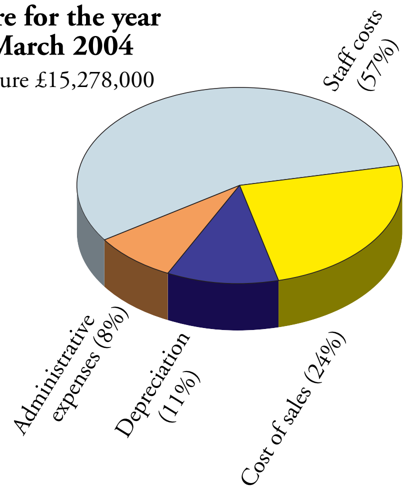
Income for the year ended 31 March 2004

Total income £15,343,000



Expenditure for the year ended 31 March 2004

Total expenditure £15,278,000



Balance sheet at 31 March 2004 **Total value £27,223,000**

Assets

Fixed assets	95 %
Stocks	0 %
Debtors	5 %

Liabilities

Capital reserve	87 %
Income & expenditure account	2 %
Current liabilities	11 %

Statement of environmental policy

The Scottish Crop Research Institute (SCRI) is an internationally recognised plant research and biotechnology centre. It carries out strategic and applied research on agricultural, horticultural, and industrial crops and on the underlying biological processes common to all plants. Mylnefield Research Services Limited (MRS) is the commercial arm of SCRI and the SCRI Environmental Management System also applies to MRS.

SCRI acts to prevent pollution and regularly assesses and reviews any environmental impacts its activities may cause. Operational control procedures are in place and objectives and targets are set to achieve continual environmental improvement. Resources are made available to implement and maintain the policy. The setting and review of environmental objectives and targets are carried out annually at the environmental management meeting and as required throughout the year in the event of changes in work activities which affect the environment.

SCRI complies with all relevant legislation and regulatory requirements, as well as to the other requirements to which it subscribes. These are listed in the *Register of legislation relating to SCRI's environmental aspects* (document ENV/SOP/001).

The policy is communicated to all members of staff, with relevant training provided to increase environmental awareness and reduce pollution throughout the Institute.

The policy is also communicated to the public by means including the SCRI website and Annual Report.

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 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 Crop Research Institute includes MRS and BIOSS.

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.

The Governing Body

Professor Bernard King, M.Sc., Ph.D., F.I.W.Sc., C.Biol., F.I.Biol., (Chairman), 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 Board Member of Scottish Enterprise Tayside and a Governor of the Unicorn Preservation Society. 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.

Mr Edward 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 is a member of the Chairman's Committee and the Remuneration Committee, and is also a Director of Mylnefield Research Services Limited. He was appointed to the Governing Body of SCRI in 2000.

Dr Martin Battersby, B.Sc., D.Phil., has spent much of his career in agribusiness working with ICI, Zeneca and Syngenta in the UK and USA. Having recently left Syngenta he has set up his own consultancy business in the field of bioscience particularly for global agriculture. A biochemist by training his recent work for Zeneca and Syngenta has included directing gene and chemical discovery strategies and managing collaborative research investments. He was appointed to the Governing Body of SCRI in 2003.

Professor David Boxer, B.Sc., Ph.D., is currently Vice Principal (Research and Enterprise) at Dundee University. He has held a number of positions at Dundee University including Dean of Faculty of Science and Engineering and Chairman of the Biochemistry Department. He has been Professor of Microbial Biochemistry at Dundee University since 1990. He has led a reappraisal of Dundee University's academic and financial priorities to produce a blueprint for the future management of the University and has been a major player in establishing a wide ranging and novel partnership agreement with another Scottish university. He was appointed to the Governing Body of SCRI in 2003.

Professor Richard 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 is a member of the Chairman's Committee, and chairs the Governing Body Science sub-committee. He is also a Director of Mylnefield Research Services Limited and is a Trustee of the Mylnefield Trust. He was appointed to the Governing Body of SCRI in 1997.

Dr Keith Dawson, B.Sc., Ph.D., D.I.C.P., is Principal Crop Consultant at the Scottish Agricultural College. He was previously 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 is a member of the Governing Body Science Sub Committee. He was appointed to the Governing Body of SCRI in 2000.

Dr Mervyn 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 four years, he joined Unilever plc where he spent 25 years mainly in their agribusiness operations, eventually becoming Chairman, in sequence, of two agribusiness subsidiary companies. The first was based in Scotland and the second in Malaysia. He retired from Unilever in 1999. He is a member of the Governing Body Audit Committee and Risk Committee. He was appointed to the Governing Body of SCRI in 2000.

Mrs 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 was a member of the Accounts Commission for Scotland from 1994 until 2002 and is a member of the Standards Commission for Scotland. She is a member of the Chairman's Committee. She was appointed to the Governing Body of SCRI in 2000.

Mr Keith 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 and large landed estates. His firm, with eight partners, now has three offices, located in Forfar, Perth and Dundee, and employs over 60 staff. Mr Hopkins specialises in capital taxes, agricultural law and cooperatives, business development, writes for the agricultural press, and lectures throughout Scotland. He is a member of the Institute of Chartered Accountants in England and Wales, a member of the Institute of Chartered Accountants of Scotland, a member of the Society of Trust and estate Practitioners, a member of the Institute of Directors, a member of the Rotary Club of Kirriemuir and Chairman of the charity Childlink Scotland. He is involved in a number of charitable organisations. He is the Chairman of Angus Farmers Markets. He is Chairman of the Governing Body Audit Committee. He is also a Director of Mylnefield Research Services Limited and is a Trustee of the Mylnefield Trust. He was appointed to the Governing Body of SCRI in 1997.

Dr Thomas Jolliffe, B.Sc., Ph.D., is currently General Manager and Managing Director of Advanta Seeds. Having studied for his PhD while working at the John Innes Institute he has several years experience in the seeds industry, particularly in relation to quality systems, breeding of European cereals and marketing and sales of forage products. He was appointed to the Governing Body of SCRI in 2003.

Mr Ian 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 is a member of the Governing Body Risk Committee. He was appointed to the Governing Body of SCRI in 2000

Emeritus Professor Sir John 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 Chairman of the Scientific Advisory Group set up to advise the Defra Chief Scientist. 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 is a member of the Chairman's Committee and the Remuneration Committee. He is also a Director of Mylnefield Research Services Limited and is a Trustee of the Mylnefield Trust. He was appointed to the Governing Body of SCRI in 1998.

Dr Michael Morgan, B.A. Ph.D., has recently retired from the Wellcome Trust where he had been working as the Director of Research Partnerships and Ventures and Chief Executive of the Wellcome Trust Genome Campus in Cambridge. A key part of his role was developing new partnerships outwith the University based research supported by the Wellcome Trust. He has also held a number of Directorships and is a Trustee of the Institute for Cancer Research. His background is in biochemistry and recent initiatives he has been involved with include the International

Human Genome Sequencing Project, the Structural Genomics Consortium and the new UK synchrotron DIAMOND being built at the Rutherford Appleton Laboratory. He was appointed to the Governing Body of SCRI in 2003.

Professor Steve Parry, B.Sc., Ph.D., is the Director of Frozen Foods Research and Sustainable Agriculture Research at Unilever Colworth R&D in Bedfordshire. Having started his career working in animal health and later medical diagnostics he changed career direction with a move to Unilever's Frozen Foods division in 1995. His current role includes having direct responsibility for the Frozen Foods Category Research Unit and being the Sustainability Research Leader as well as having responsibility for the Colworth Farm. He is also a visiting professor of Biological Sciences at Essex University specialising in the area of sustainability and has recently joined the World Bank Steering Group for the Assessment of Science and Technology for Global Agriculture. He was appointed to the Governing Body of SCRI in 2003.

Professor George Salmond, B.Sc., M.A., Ph.D., F.R.S.A., is currently Professor of Molecular Microbiology in the Biochemistry Department at the University of Cambridge, and a Professorial Fellow of Wolfson College. His research group is working on various aspects of molecular microbiology and genetics including quorum sensing, global gene regulation, bacterial virulence and antibiotic regulation and synthesis in the plant pathogen (Erwinia). He has industrial experience from working for a chemical biotechnology company in the USA and has also served on the Scientific Advisory Board of NSC Technologies in the USA. In addition Professor Salmond has been Chairman of a number of BBSRC and SEERAD committees and is currently a member of the Governing Council of the John Innes Centre. He was appointed to the Governing Body of SCRI in 2003.

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 Innovative Manufacturing Committee. He is a member of the Governing Body Science Committee. He joined the Governing Body of SCRI in 1995.

Staff list as at 31 March 2004

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
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.[1,9]	Band 3
P.F. Palukaitis, B.Sc., Ph.D.[6,12,20]	Band 3
M. Taliansky, Ph.D, DSc.[21]	Band 3(IMP)(Prom. Jul 03)
H Barker, B.Sc., Ph.D.[9]	Band 4
C.G. Simpson, B.Sc., Ph.D.	Band 4
T Canto, B.Sc., Ph.D.	Band 5 (SPD)
P. Hedley, B.Sc., Ph.D.	Band 5 (SPD)
B. Reavy, B.Sc., Ph.D.	Band 5 (SPD)
G.G. Simpson, 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)
A. Dolan, H.N.C.	Band 6
M.M. Swanson, B.Sc., Ph.D.	Band 6 (P/T)
S.F. Blackie, B.Sc.	Band 7
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
W.J. McGavin, B.Sc.	Band 7
K.D. McGeachy, H.N.C.	Band 7 (P/T)
J. Middlefell-Williams, H.N.C.	Band 7
J. Morris, H.N.D., B.Sc.	Band 7
D. Davidson	Band 8 (P/T)
G.L. Fraser	Band 8 (P/T)
J.D. Fuller	Band 8
M.S. Liney, H.N.D.	Band 8 (P/T)
L. Donnelly	Band 9
DNA Sequencing / Genotyping Facility	
C. Booth, B.Sc.	Band 7
Media Kitchen	
W. Ridley	Band 7
M Burton	Band 9
E. Warden, O.N.C.	Band 9
W. Burry	Band 11 (HELM)
J. McMillan	Band 11 (P/T) (HELM)
Administrator	
A. Addison	Band 7
Defra	
M.R. MacLeod, B.Sc., Ph.D.	Band 6 (PD)
Leverhulme	
S.H. Kim, B.Sc., Ph.D.	Band 6 (PD)
EU	
D. Lewandowska, B.Sc.	Band 6 (PD)
B. Obert, M.Sc., Ph.D.	Band 6 (PD)

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

Programme Leader: K.J. Oparka, B.Sc., Ph.D.[6]	Band 2 (IMP)
Associate Programme Leader:	
A.G. Roberts, B.Sc., Ph.D.[9]	Band 5 (SPD)(Prom. Jul 03)
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)
T.L. Gillespie, B.Sc., Ph.D.	Band 6 (PD)
K. Hrubikova, M.Sc., Ph.D.	Band 7
F. Carr, O.N.C., H.N.D.	Band 8
J. Tilsner	Band 11
Administrator	
M. Pearson, B.Sc.	Band 8
SEERAD FF	
M.J.M. Latijnhowers, B.Sc., Ph.D.	Band 6 (PD)
Proof of Concept	
E.F.O. Randall, M.Sc., Ph.D.	Band 6 (PD)
K. Wypijewski, M.Sc., Ph.D.	Band 6 (PD)
Gatesby	
K. Bell, B.Sc., Ph.D.	Band 6 (PD)
K. Jackson, B.Sc.	Band 7
EU	
K.S. Pradel, B.Sc., Ph.D.	Band 6 (PD) (P/T)

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 4
V.C. Blok, B.Sc., M.Sc., Ph.D.	Band 4
J.T. Jones, B.Sc., Ph.D.[9]	Band 4 (Prom. Jul 03)
A. Kumar, B.Sc., Ph.D.	Band 4
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
B. Williamson, B.Sc., M.Sc., Ph.D., D.Sc.[9]	Band 4
A. Ziegler, B.Sc., Ph.D.	Band 5 (SPD)
L. Pritchard, B.Sc., Ph.D.	Band 6 (PD)
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., Ph.D.	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)
Administrator	
M. Murray	Band 8
SEERAD Fellowship	
S. Whisson, B.Sc., Ph.D.	Band 5 (SPD)
SEERAD FF	
M. Armstrong, B.Sc., Ph.D.	Band 6 (PD)
A.O. Avrova, B.Sc., PhD.	Band 6 (PD)
H. Liu, M.Sc.	Band 6 (PD)
E. Venter	Band 6 (PD)
L.M. Castelli, B.Sc., M.Sc.	Band 6
V. Young, B.Sc.	Band 7 (P/T)
EU	
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
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
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)
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.J.M. 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.D.	Band 8
D. McRae, O.N.C.	Band 8
P.L. Smith, B.Sc.	Band 10 (P/T)
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
D.C. Lloyd, B.Sc., M.Sc.	Band 8 (P/T)
Defra	
S. Haupt, Dip.Biol.	Band 6 (PD)
S.D.A. Pont, B.Sc.	Band 10
FSA	
K. Harper, B.Sc., Ph.D.	Band 6 (PD) (P/T)
M.G. Anderson, B.Sc., M.Sc.	Band 8
P. Neave, O.N.C.	Band 10
EU	
S.C. Conner, B.Sc., M.Sc., C.Chem., M.R.S.C.	Band 6
P.M. Dobson,	Band 10
Proof of Concept	
G.D. Hunter, B.Sc., Ph.D.	Band 6 (PD)
M.H. Nuopponen, M.Sc.	Band 6
J. Shaw, B.Sc.	Band 7
G.M. Birch, B.Sc.	Band 9
Glaxo SmithKline	
P.G. Walker, H.N.D.	Band 8

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.[5,6,7,9,18]	Band 2
R.M. Brennan, B.Sc., Ph.D.	Band 4
G. Bryan, B.Sc., Ph.D.	Band 4
M.F.B. Dale, 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
K. McLean, B.Sc.	Band 6
A. Booth, H.N.C.	Band 7
S.L. Gordon, H.N.C.	Band 7
J. Lyon	Band 7
N. McCallum, B.Sc.	Band 7
G. McKenzie, H.N.D., B.Sc.	Band 7
J. McNicoll, H.N.C., B.Sc.	Band 7
M. Macaulay, H.N.C., B.Sc.	Band 7
K. Smith, Dip.H.E.	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 (P/T)
R. Keith, N.E.B.S.M.	Band 8
P.E. Lawrence	Band 8
H.A. Mathews	Band 8
M. Myles, O.N.C.	Band 8
S.L. Williamson, B.Sc.	Band 8
J. Brown	Band 9
A.M.S. McInroy	Band 9 (P/T)
G. Wilde	Band 9
Administrator	
S. Forsyth	Band 8
SEERAD FF	
A. Druka, M.Sc., Ph.D.	Band 5 (SPD)
M. Woodhead, B.Sc., Ph.D.	Band 6 (PD)
I.M. Tierney, B.Sc., M.Sc.	Band 7
BBSRC	
N. Rostoks, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
S. Mudie, B.Sc.	Band 8
EU	
Y. Hashim, B.Sc., Ph.D.	Band 6 (PD)
L.J. Duncan, B.Sc.	Band 8
FSA	
A. Ibrahim, B.Sc., Ph.D	Band 5 (SPD)
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)
A.J. Karley, B.A., D.Phil. 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/SEERAD
D. Cullen, B.Sc., Ph.D. Band 6 (PD)
A. Garside, B.Sc., M.Phil. Band 7
J.N. Anderson, B.Sc., Band 8

Defra
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

EU
M. Elliott, B.Sc. Band 6 (PD)

Programme 7 – Plant-Soil Interface (PSI)

Programme Leader: B.M. 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
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)
C.M. Scrimgeour, B.Sc., Ph.D.[9] Band 5 (SPD)
R. Neilson, H.N.C., M.Sc., Ph.D. Band 6 (PD)
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 7
J. Davidson, B.Sc. Band 7 (P/T)
S. Mitchell, B.Sc. Band 7
S. Regan, B.Sc., M.Sc. Band 8 (P/T)

Administrator
S. Inglis Band 7

SEERAD FF
N. Nunan, B.Sc., M.Sc., Ph.D. Band 6 (PD)
J. Wang, 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.N. Humphris, H.N.C., B.Sc., Ph.D. Band 6 (PD)
S. Regan, B.Sc., M.Sc. Band 7 (P/T)

EU
S. Caul, H.N.C. Band 6
J.A. Thompson, B.Sc. Band 8

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

Programme Leader: A.C. Newton, B.Sc., Ph.D. Band 4

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
G.L. Malloch, D.C.R., B.Sc., Ph.D. Band 6
R.M. Solomon-Blackburn, B.A., M.Sc. Band 6
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

Administrator
M. Murray Band 8

SEERAD FF
J. Wishart, B.Sc., Ph.D. Band 7

EU
L. Schena, Ph.D. Band 5 (SPD)

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

Administrator
M. Pearson, B.Sc. Band 8

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: N.G. Hattersley, B.Sc., Ph.D., A.C.M.A. Band 4

Unit of Finance and Human Resources (FHR)

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
K. Muir	Band 10 (P/T)
S. Smart	Band 10 (P/T)

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
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
S.K. Thomson, H.N.D., B.A.	Band 8
L. Fiddes, H.N.C.	Band 9
Safety Coordinator: M.J. De,Maine, B.Sc., M.Phil.	Band 5

Unit of Information Technology (IT)

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Operations Manager: S. Clark, H.N.C., M.Sc.	Band 5
P.J.R. Grimmond, B.A.	Band 6
P. Smith, B.Sc.	Band 6
L.H. Davidson, B.A.	Band 7
L.A. McGregor, B.Sc.	Band 8

Unit of Engineering and Maintenance (EM)

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D. Gray, H.N.C.	Band 6
A. Low	Band 6
I.C. McNaughton, H.N.C.	Band 6
K.A. Henry	Band 7
R.D. McLean	Band 7
G.C. Roberts	Band 7
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
G.J.E. Ewart	Modern Apprentice
E. Millar	Band11 (P/T)
G. Pugh	Band 11 (P/T)
V. Tait	Band 11 (P/T)
Administrator	
W.A. Patterson, H.N.D.	Band 8

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

Biomathematics and Statistics Scotland (BioSS)

Acting Director: D.A. Elston, B.A., M.Sc., Ph.D. — Band 4

King's Buildings, University of Edinburgh

C.A. Glasbey, M.A., Dip. Math. Stats., Ph.D., D.Sc., M.I.S.I.[16,17,18]	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
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. Holtrop, M.Sc., Ph.D.	Band 5 (SPD) (P/T) (Prom. Jul 03)

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
F.G. Wright, B.Sc., M.Sc., Ph.D.	Band 4 (SPD)(Prom. Jul 03)
K.M. MacKenzie, B.Sc., M.Sc., Ph.D.	Band 6 (PD)
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 Manager: 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., M.B.A.
Personal Secretary/Administrative Assistant: H. Wilson.
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
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L. Ferguson
L. Hunter, B.Sc.
S.N. Jennings, B.Sc.
R. Razzo,
C.M. Reid, B.Sc.
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.
J. Bown, B.Sc., Ph.D.
F. Bransby, B.A., M.A., Ph.D.
W.C. Christie, M.B.E., B.Sc., Ph.D., D.Sc., C.Chem., F.R.S.E., F.R.S.C.
J.M. Duncan, B.Sc., Ph.D.
R.P. Ellis, B.Sc., Ph.D.
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.
A.T. Jones, B.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.
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
Q. Chen	PPI	6	March 03
L. Deeks	PSI	6 PD	May 03
N. Deighton	QHN	5 SPD	May 03
B. Dixon	PPI	6 PD	April 03
S.L. Jain	QHN	11	February 04
A. Masoudi-Nejad	GD	6 PD	August 03
F. Mitchell	EM	11	June 03
J. Oparka	QHN	11	September 03
P. Proudlock	QHN	7	November 03
A. Purvis	GD	6 PD	January 04
J.A. Sinclair	HPCE		November 03
T. Spiers	CB	6	June 03
V. Stubbs	PSI	6 PD	July 03
M. Torrie	EGFS	11	August 03
J.D. Watt	FHR	3	October 03

Staff Retirements

Name	Unit	Band	Month
W. Pollock	EM	11	January 04
A.T. Jones	HPCE	3	January 04
R.P. Ellis	GD	4	February 04
B.A. Goodman	QHN	4	June 03
J. Lawrence	EM	11	August 03
B. Boag	PSI	4	August 03
J.M. Duncan	HPCE	3	December 03

Deaths

Name	Unit	Band	Month
R.A. Kempton,	BioSS	3	May 03

Redundancies, Flexible & Compulsory Retirements

Name	Unit	Band	Month
G.H. Duncan	CCC	5	March 03
T.G. Geoghegan	SLIS	5	March 03
D.L. Hood	FHR	6	March 03
W.D.J. Jack	EGFS	7	March 03

Name	Unit	Band	Month
D.S. Petrie	EGFS	7	March 03
G. Pugh	EGFS	8	September 03
G. Wood	EGFS	4	March 03

Postgraduate Students

Name	Unit	Subject
M.A.M. Adam	PPI	Identification and molecular characterisation of root knot nematodes.
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.
C. Clyne	HPC	Genome analysis of peach potato aphid *(Myzus persicae).*
J. Comadran Trabal	GD	Mapping adaptation of barley to drought environments (MABDE).
L.J.M. Ducreux	QHN	Manipulation of carotenoid metabolism in tubers of *Solanum tuberosum* and *S. phureja* using an antisense approach.
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.
L. Kasprowicz	HPC	The population dynamics and ecophysiology of the peach-potato aphid *Myzus persicae.*
H. L Kuan	PSI	What is the link between microbial diversity and soil resilience?
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.
L. Moleleki	PPI	Cellular localisation and function of TTSS secreted proteins in Erwinia.
W.L. Morris	QHN	Characterisation and manipulation of gene expression during carotenogenesis in potato tubers.
M. Nadella	PSI	Mechanisms involved in biocontrol of wood decay fungi by volatile organic compounds (VOC's) from Trichoderma species.
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.G. Anderson	UK	QHN	October 03	6 months
M. Andrews	UK	HPCE	May 03	3 months
S. Beng Kah	Malaysia	GD	February 04	10 months
J. Bigot	France	BioSS	April 03	5 months
J. Black	UK	HPCE	May 03	3 months
N.V. Chichkova	Russia	GE	March 04	2 weeks
C. Clyne	UK	HPCE	June 03	3 months
N. Costigan	UK	PPI	July 03	3 months
P. Cramb	UK	HPCE	July 03	1 month
O. Danci	Romania	PPI	October 03	11 months
R. Davidson	UK	BioSS	October 03	6 months
R. Davies	UK	QHN	June 03	3 months
R. Davies	UK	QHN	July 03	1 month
M. Dinesen	Denmark	CCC	August 03	2 months
S. Donn	UK	PSI	July 03	4 months
V. Dunbabin	Australia	PSI	May 03	6 weeks
G. Duncan	UK	PSI	February 04	3 months
C. Durajczyk	UK	PPI	July 03	3 months
E. Fanelli	Italy	PPI	January 03	4 months
S. Fyffe	UK	QHN	June 03	2 months
R. Ghalamfarsa	Iran	HPCE	November 03	10 months
S. Ghasemi	Iran	PPI	September 03	11 months
A. Gillies	UK	PPI	June 03	4 months
T. Goody	UK	QHN	August 03	6 months
O. Hamza	UK	PSI	June 03	6 months
N. Houston	UK	HPCE	July 03	1 month
A. Jayasekera	Sri Lanka	GD	May 03	1 month
C.S. Jung	USA	GD	October 03	1 month
I. Karanastasi	Greece	HPCE	June 03	1 month
L. Kasprowicz	UK	HPCE	July 03	3 months
C. Kimber	UK	GE	June 03	10 weeks
M. Koprivica	Yugoslavia	HPCE	September 03	1 month
K. Kovacs	Romania	PPI	October 03	1 month
A. Latz	Germany	CCC	February 04	2 weeks
O. Lavrova	Russia	PPI	May 03	2 months
D. Lloyd	UK	QHN	December 03	6 months
K. Loades	UK	GD	June 03	3 months
C. McMurran	UK	QHN	April 03	6 months
M. Mackay	UK	PSI	June 03	2 months
B. Martin	Spain	HPCE	August 03	3 weeks
C. Mobray	UK	HPCE	June 03	3 months
G. Muir	UK	HPCE	June 03	3 months
M. Nadella	India	PSI	February 04	10 months
A. North	UK	BioSS	May 03	4 months
J. Oparka	UK	QHN	June 03	2 months
R. Oparka	UK	QHN	June 03	2 months
M. Opik	Estonia	PSI	March 04	8 weeks
R. Pack	UK	QHN	May 03	4 months
T. Palm	Germany	PPI	September 03	7 months
H-C. Park	South Korea	GE	December 03	5 months
J. Paulo	Netherlands	BioSS	October 03	4 weeks
S. Perrier	UK	QHN	June 03	3 months
S.D.A. Pont	UK	QHN	June 03	6 months
R. Powell	UK	QHN	June 03	3 months
L. Pylypenko	Ukraine	PPI	June 03	1 month
S. Ranomenjanahary	Madagascar	PPI	June 03	3 months
W. Ratman	Malaysia	GD	February 04	1 week
R. Reverte	Spain	HPCE	January 04	6 months
E. Riga	USA	HPCE	August 03	6 weeks
A. Sharma	UK	QHN	April 03	6 months
F. Shpiro	UK	QHN	July 03	1 month
D. Skulikas	UK	GD	June 03	4 months
A.M. Smith	UK	HPCE	July 03	1 month
I. Soderby	Denmark	CCC	July 03	1 month
S. Sturrock	UK	BioSS	December 03	4 months
S.S. Sundaramurthy	Sri Lanka	GD	October 03	6 months
N. Tatipalli	India	PSI	March 03	6 months
S. Tatipamula	India	PSI	March 03	6 months
J. Tilsner	Germany	CCC	January 04	3 months
J.F. Uhrig	Germany	GE	August 03	2 weeks
A.B. Vartapetian	Russia	GE	March 04	2 weeks
A. Verhee	France	QHN	May 03	3 months
P. Veronico	Italy	PPI	September 03	1 month
M. Vicente	Portugal	PPI	January 03	12 months
L. Wirthmueller	Germany	PPI	October	4 months
X. Zhu	Sweden	BioSS	September 03	3 months

Longer-Term Visitors & Research Fellows

Name	Country of origin	Programme	Month/yr of arrival	Length of stay
S. Alberino	Italy	QHN	November 03	1 year
M. Barciszewska-Pacak	Poland	CCC	February 03	1year
B.N. Chung	South Korea	GE	January 04	1 year
M. Chechalina	Uzbekistan	GD	June 03	1 year
C. Johnstone	UK	EMB	Aug 02	3 years
P. Sharma	India	GD	April 03	1 year
S. Yoshida	Japan	PSI	March 04	1 year

Editorial Duties

Name	Position	Journal Title
H. Barker	Editorial Board	Annals of Applied Biology
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
H.V. Davies	Editorial Board	Phytochemistry
D.A. Elston	Associate Editor	Applied Statistics
	Associate Editor	Journal of Agricultural, Biological and Environmental Statistics
S.C. Gordon	Joint Editor	IOBC/wrps Bulletin
	Editorial Board	Acta Horticulturae
C.A. Glasbey	Editor	Applied Statistics
J. Graham	Associate Editor	Journal of Horticultural Science and Biotechnology
B.S. Griffiths	Editorial Board	Pedobiologia
P.D. Hallett	Editorial Board	Pedosphere
J.R. Hillman	Publication Committee	Journal of Horticultural Science
	Editorial Board	Agricultural Systems
	Editorial Board	Journal of Agricultural Science
G.W. Horgan	Statistical Editor	British Journal of Nutrition
D. Husmeier	Referee	Bioinformatics
	Referee	Neural networks
J.T. Jones	Editorial Board	Journal of Helminthology
	Editorial Board	Nematology
	Editorial Board	International Journal for Parasitology
J.W. McNicol	Senior Statistical Editor	Annals of Applied Biology
M.A. Mayo	Editor	Archives of Virology (Virology Division News)
	Editorial Board	Virology
	Referees Panel	Nucleic Acids Research
	Abstractor	Vitis
	Senior Editor	Journal of Plant Pathology
R. Neilson	Editorial Board	Annals of Applied Biology
	Deputy Chief Editor	Russian Journal of Nematology
	Editorial Board	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
	Editorial Board	Molecular Plant-Microbe Interactions
M.S. Phillips	Assistant Editor	Nematology
W. Powell	Associate Editor	Molecular Ecology
D.J. Robinson	Editor	Descriptions of Plant Viruses
	Editorial Board	Journal of Virological Methods
D. Stewart	Advisory Board	Cellulose Chemistry and Technology
M. Taliansky	Editorial Board	Journal of General Virology
M.A. Taylor	Editorial Board	Plant Growth Regulation
I. Toth	Assistant Editor	Molecular Plant Microbe Interactions
R. Waugh	Editorial Board	Plant Biotechnology Journal
B. Williamson	Deputy Chairman	Annals of Applied Biology
F.G. Wright	Editorial Board	Heredity

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
	Member	Executive Committee, LEAF Scotland
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	Member	Berry Scotland advisory group
S. Brocklehurst	Member	HRI Ethical Review Committee
G.J. Bryan	Advisor / Committee Member	USA NSF Potato Genome Project
H.V. Davies	Member	European Food Safety Authority, GM Panel
	Member	Defra HortLink Programme Management Committee
M.J. De,Maine	Member	BBSRC Joint Committee on Health & Safety
	Member	SABRI Safety Officers' Group
D.A. Elston	Member	Scientific and Technical Advisory Group, UK Environmental Change Network
	Chair	Royal Statistical Society Highland Local Group
	Member	Advisory Committee for U. York Mres Course 'Mathematics in the Living Environment'
B.P. Forster	Chairman	COST Action 851, EU
C.A. Glasbey	Member	EPSRC Peer Review College
	Member	Conference Advisory Committee of International Biometric Society
	Member	Royal Statistical Society Editorial Policy Board
	Member	Royal Statistical Society Programme Committee
	Member	Programme Committee for French-Danish Workshops on Spatial Statistics and Image Analysis in Biology
S.C. Gordon	Working Group Chairman	COST ACTION 836
J. Graham	Advisor	HDC Soft Fruit Panel
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)
G.W. Horgan	Member	Royal Statistical Society Highlands Group
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
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	Member	Association of Applied Biologists, Virology Group Committee
	Member	Society for General Microbiology, Virus Group Committee

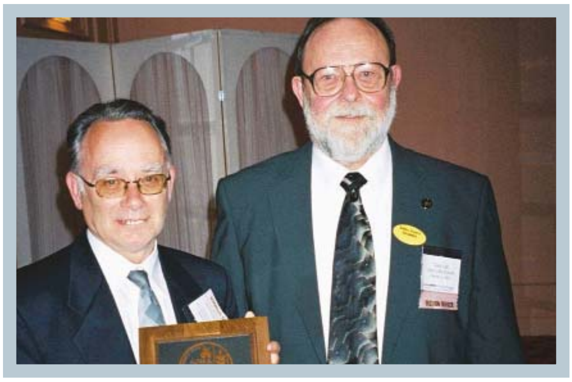
Name	Position	Committee or Organisation
U.M. McKean	Joint Chair	Scottish Agricultural Librarians' Group
G.R. Marion	Module Head	Project Coordination Committee EU FP6 Project: ALARM
M.A. Mayo	Executive Committee Member	ICTV
	Secretary	ICTV
	Chairman	ICTV Study Group on satellite taxonomy
	Member	ICTV Study Groups on luteoviruses and unclassified viruses
	Member	IUBS/IUMS International Committee on Bionomenclature
R. Neilson	Governing Board Member	European Society of Nematologists
I.M. Nevison	Statistician	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
P.F. Palukaitis	Member	ICTV Satellite Study Group
	Member	ATCC Tobamovirus Advisory Group
	External examiner	National University of Singapore
	External examiner	University of Auckland
	External examiner	Queen's University, Belfast
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 Lin k Programme
G. Ramsay	Member	UK Plant Genetic Resources Group
	Member	Review Committee, UK Potato Quarantine Unit
A.G. Roberts	Secretary	Royal Microscopical Society, Cell Biology Section
	Science Ambassador	SETNET Scotland (TechFest)
D.J. Robinson	Member	ICTV Tobamovirus & Tobravirus Study Group
	Member	ICTV Umbravirus Study Group
G.R. Squire	Member	Sustainable Arable Link
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
	Secretary	Research Councils Library and Information Consortium (RESCOLINC)
	Chair	BBSRC Research Institutes Librarians Committee (BRILCOM)
J.S. Swanston	Secretary	SSCR Cereal Crops Sub-Committee
	Member	NFU (Scotland) Biofuels Committee
M. Taliansky	Chairman	Umbravirus Group, International Committee of Taxonomy and Classification of Viruses
	Adjunct Professor	Moscow State University
M.A. Taylor	Member	International Carotenoid Symposium Organising Committee
W.T.B. Thomas	Member	BSPB Cereal Crop Group
L. Torrance	Member	Plant Virus Subcommittee, International Committee Taxonomy of Viruses
	Chairman	Furovirus and allies Study Group. International Committee Taxonomy of Viruses
	Member	Evaluation Committee, Czech Academy of Sciences
I.K. Toth	Committee Member	BSPP President's Meeting
	SCRI Representative	SEERAD Genomics Taskforce
R. Viola	Chairman	European Association for Potato Research (Physiology Section)
	Secretary	Mylnefield Trust
	SABRI Representative	BBSRC Joint Negotiating and Consultative Committee
R. Waugh	Member	ITMI Steering Group
	Member	SEERAD Genomics Task Force
	Scientific Executive Member	ERA-NET Plant Genomics
B. Williamson	Treasurer	Association for Crop Protection in Northern Britain
F.G. Wright	Member	CCP11 Bioinformatics Committee
	Member	SEERAD Genomics Task Force

Awards and Distinctions

Name	Programme	Degree/Award/Distinction/Appointment
Habeba Al-Meniae	GD	PhD University of Reading. The influence of micro-organisms on structural generation in direct drilled and ploughed soils.
Lydia Castelli	PPI	PhD University of Dundee. Novel sources of resistance to the potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*) from wild potato species held in the Commonwealth Potato Collection
Bill Christie	Research Fellow	Bailey award of the American Oil Chemists' Society (AOCS)
Marcelo de Oliveira	HPC	SABRI Postgraduate Competition Winner
Howard Davies	QHN	Gates Foundation Award
Jim Duncan	HPC	MBE
Bernard King	Chair, Governing Body	CBE
Jackie Heilbronn	PPI	PhD University of Dundee. Discovering resistance pathways in response to elicitors and powdery mildew attack in barley
Maria Holeva	PPI	PhD University of Dundee. A molecular study of the type III secretion system in *Erwinia carotovora* subsp. *atroseptica*
Sonia Humphris	PSI	PhD University of Abertay. An investigation of the production of volatile organic compounds (VOCs) by *Trichoderma spp.* and their mode of action against *Serpula lacrymans.*
Ling Kuan	PSI	PhD University of Aberdeen. Resilience of soil microbial community function in an upland grassland soil
Hazel McGovern	PSI	PhD Cranfield University. The influence of micro-organisms on structural generation in direct drilled and ploughed soils.
Donald MacKerron	Research Fellow	MBE
Derek Stewart	QHN	Proof of Concept Award. The Proof of Concept Fund is managed by Scottish Enterprise and from the European Regional Development Fund. The Proof of Concept Fund supports the pre-commercialisation of leading-edge technologies emerging from Scotland's Universities, research institutes and NHS Trusts
John Whitehead	Chair, SSCR	OBE

SCRI Students gain University of Dundee PhDs.

Donald MacKerron celebrates with his family on receiving his MBE.



Bill Christie receives the Bailey award of the American Oil Chemists' Society (AOCS) from Dr Gary List, Chairman of the North Central Section of the American Oil Chemists' Society.

Derek Stewart receives the Proof of Concept Award

SCRI Research Programme
2003-2004

SEERAD funded research programme showing: Commissioning number; Title; 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.

Core funded programme

SCR/538/00	Optimising production and biodiversity of arable plants and invertebrates at patch and landscape scales. I. Arable plants	Squire G
SCR/540/00	Genetics of cultivated potatoes	Bradshaw J E
SCR/541/00	Genetic approaches to evaluation and utilisation of soft fruit germplasm	Brennan R
SCR/545/00	Detection, diversity and epidemiology of important viruses and their vectors in berryfruit crops and strategies for their effective control	Jones A T
SCR/557/01	Targeted long-distance transport of macromolecules in plants	Oparka K
SCR/558/01	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	Molecular biology of potato leafroll virus: aphid transmission and the establishment of infection in host plants	Barker H
SCR/560/01	Molecular bases of resistance and susceptibility in potato and barley	Birch P R J
SCR/561/01	Molecular bases of pathogenicity in potato cyst nematodes, *Xiphinema index* and *Phytophthora infestans*	Jones J
SCR/562/01	Genetics of seedling root traits in barley	Forster B
SCR/563/01	Conservation and utilisation of the Commonwealth Potato Collection	Mackay G R
SCR/564/01	A gene map of the interval between GP21 and GP179 on potato linkage group V	Bryan G
SCR/565/01	Identification and characterisation of bacterial artificial chromosome (BAC) clones from gene rich regions of the barley genome	Waugh R
SCR/566/01	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	Ecological management and biotechnology	Squire G
SCR/572/01	Computational biology	Marshall D F
SCR/573/01	Functional analysis of novel genes from potato and barley	Lacomme C
SCR/574/01	Development and application of metabolic profiling technologies to enhance the understanding of metabolic and developmental processess in plants	Deighton N
SCR/575/01	Enhancing food quality and nutritional value through multidisciplinary approaches which exploit genetic and molecular diversity	Taylor M
SCR/576/01	Sequence diversity and horizontal genomics (targeted gene discovery)	Waugh R
SCR/577/01	Molecular plant diversity and germplasm resources	Waugh R
SCR/578/01	Parallel gene expression technologies supporting the discovery of plant and pathogen genes important to agriculture and biotechnology	Machray G C
SCR/580/02	Suppression of gene silencing by virus proteins	MacFarlane S

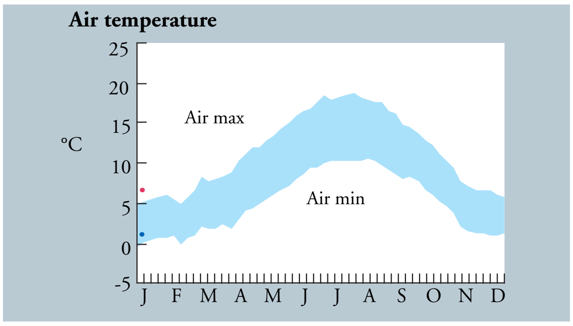
SCR/581/02	Cell and tissue engineering in barley and potato	Machray G C
SCR/583/02	Variation in pathogenicity in *Globodera* spp. in relation to host resistance	Phillips M S
SCR/584/02	Approaches to regulate the L-ascorbic acid content of commercially important plants	Viola R
SCR/585/02	Genetics of cultivated diploid potatoes	Bradshaw J E
SCR/586/02	Cell-to-cell trafficking of macromolecules in plants	Oparka K J
SCR/587/02	Optimising production and biodiversity of arable plants and invertebrates at patch and landscape scales. II. Invertebrates	Fenton B
SCR/590/03	Developing physiologically based models linking genetic variation among individuals to the sustainability of biodiversity at the scale of the community	Marshall B
SCR/591/03	Understanding the role and function of virus proteins in the establishment of systemic infection	Torrance L
SCR/592/03	Exploitation of barley mutant populations	Waugh R
SCR/593/03	Defining stability of host-pathogen dynamics of fungal leaf blights in heterogeneous barley and other graminaceous canopy structures	Newton A C
SCR/594/03	Biophysical and physiological interactions at the root-soil interface	Bengough A G
SCR/595/03	Interpretation and application of indicators of ecosystem sustainability	Griffiths B
SCR/596/03	Molecular mechanisms in alternative splicing	Simpson C
SCR/597/03	Population biology, molecular evolution and epidemiology of potato late blight (*Phytophthora infestans*)	Cooke D
SCR/598/03	An integrated and quantitative approach to the exploitation of sequence data from plant genomes	Marshall D
SCR/599/03	The bioavailability and bioefficiancy of soft fruit antioxidants	Stewart D
SCR/600/03	Exploration and exploitation of phytochemical diversity in the Commonwealth Potato Collection through metabolite profiling	Davies H V
SCR/601/03	Characterisation of novel genes from the *Erwinia carotovora* subsp. *atroseptica* genome sequence and their effects on corresponding genes in potato	Toth I
SCR/602/03	Nuclear dynamics and small novel RNAs in the regulation of plant gene expression	Brown J W S
SCR/603/03	Gene based marker development for exploitation in barley	Russell J
SCR/604/03	Quantifying the role of environmental perturbation and plant genotypes in creating resilient and sustainable agroecosystems	Hallet P
SCR/605/03	Interpretation of microbial functional interactions in the carbon and nitrogen cycles for the effective management of sustainable arable ecosystems	Wheatley R
SCR/606/03	Connecting barley genotype to phenotype with focus on grain quality traits	Thomas W T B
	Flexible funded programme	
SCR/516/97	Genetic mapping and molecular cloning of novel sources of resistance to *Globodera pallida*	Waugh R
SCR/522/98	Development of Rubus genotypes with transgenic resistance to raspberry bushy dwarf virus	Jones A T
SCR/555/00	Cereal transcriptome resources	Waugh R

SCR/556/00	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	Significance and mechanisms of landscape-scale gene flow	Ramsay G
SCR/569/00	Phytophthora diseases of soft fruit: determining their prevalence and the source of new outbreaks in Scotland	Duncan J M
SCR/570/00	Mechanical properties of primary cell walls by micro-stretching *in vivo*	Bengough A G
SCR/579/01	Development of robust, broad based QTL maps to improve barley breeding	Thomas W T B
SCR/582/01	Cloning of avirulence genes from the oomycete plant pathogens *Peronospora parasitica* and *Phytophthora infestans*	Birch P R J
SCR/589/02	Novel methodologies and tools for the analysis of germplasm collections	Marshall D
SCR/808/94	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.	Griffiths B S
SCR/823/97	Significance of physical heterogeneity for scaling of solute chemistry in soils from fine scale to subcatchment	Bengough G
SCR/824/97	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	Identification and assessment of nutritional relevance of antioxidant compounds from soft fruit species	Davies H V
SCR/833/00	Microsatellites as population genetic markers	Powell W
SCR/834/01	Assessment of plant germplasm for bioactive molecules	Ramsay G
SCR/835/01	Genomic sequencing and proteomic analyses of the potato pathogen *Erwinia carotovora* subsp. *atroseptica* (Eca) and the animal pathogen *Chlamydophila abortus* (Ca)	Toth I
SCR/837/01	Biodiversity: taxonomy, genetics and ecology of Sub-arctic willow Scrub	Russell J
SCR/901/02	Soil stability and resilience: the interplay between biological and physical recovery from stress	Griffiths B S
SCR/902/02	Functional characterisation of appressorial infection stage-specific proteins from *Phytophthora infestans*	Birch P R J
SCR/903/02	A comparative snp based approach to identify and mime genes controlling root traits in the Triticeae	Waugh R
SCR/905/03	Develop a satisfactory detection method for *Phytophthora fragariae* var. *rubi* and *Phytophthora idaei* in high health Rubus mother plant stocks using water eluates from potted plants	Dolan A
SCR/906/03	Factors affecting the prevalance of clones of *Myzus persicae* in Scotland, particularly those with aphicide resistance, and implications for virus control in seed potatoes	Fenton B
SCR/907/03	Viral-based functional genomics of the Golgi apparatus	Boevink P
SCR/908/03	Post genomic analysis of *Erwinia carotovora* virulence responses in *in vitro* and i*n planta* environments	Toth I

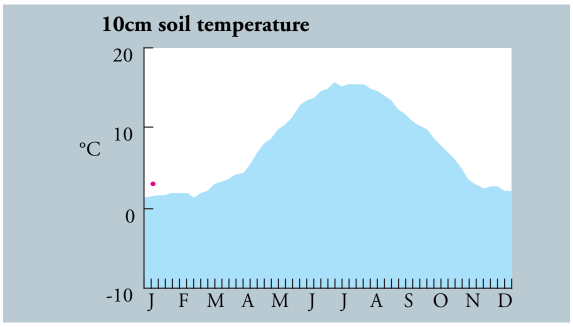
Meteorological Records

M. Grassie*

General The SCRI meteorological station was the subject of interest for approximately twenty schoolchildren in April as part of the annual 'Bring Your Child to Work' day. During a guided informative tour of the site, the children were given the opportunity to make observations, read instruments and ask questions. The 'met site' was also visited in August by eighteen P7 schoolchildren from the Dundee STEM Partnership. The children's visit was included in their trip to SCRI as part of a week-long science summer school.

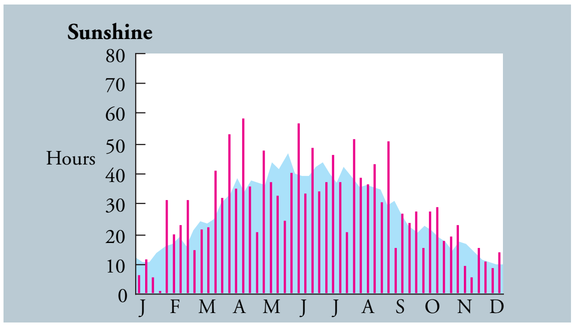


Temperature Conditions were generally warmer than normal throughout the year, without exception. Many months showed the highest average maximum temperatures for several years, the most remarkable being March (highest since 1961), and April (highest since 1955). Although the year will be remembered for its hot summer with individual days in July and August reaching 25°C and 26°C, it was remarkable in the length of the warm spell. This extended as far back as March (16.6°C on the 24th), and into autumn with 18.4°C on the 9th October.

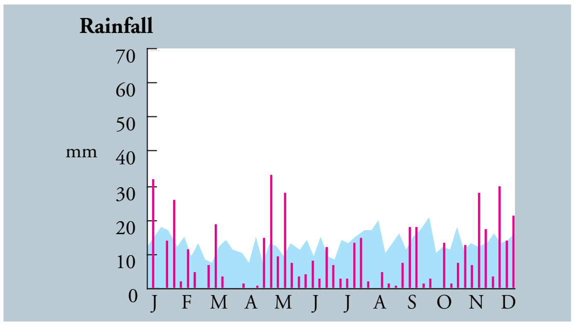


Similarly, average minimum temperatures were higher than typical with the exception of February, October and December. Only one day's frost occurred in May, against the norm of 7, while contrarily, October had 13 occurrences compared to the LTA of 9.5. Soil temperatures were also higher than the LTA with the exception of February and October.

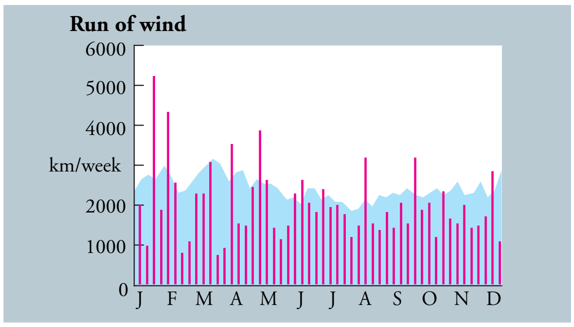
Sunshine and solar radiation Sunshine figures were higher than usual with a total of 1507.5 hours for 2003 (1411.6 LTA) the only exceptions to this being May and July, which, despite the high temperatures, received considerably less sunshine than normal (May: 148.7 hours, 188.1 LTA and July: 150.0 hours, 182.9 LTA). Solar radiation values were high but not exceptional.



Rainfall Generally, rainfall was lower than normal, the annual total reaching 472.7mm as compared to the LTA of 664.5mm, the lowest since 1989. Particularly dry were August with 8.3mm (52.3mm LTA), and October with 16.1mm (67mm LTA). The exceptions were May, November and December, which all had slightly higher rainfall than normal.



Wind Overall, windspeeds were unexceptional. The highest being the months February through to June, which all had at least 1 day with speed of 20 knots reached (representing a 'fresh breeze' on the Beaufort scale), and November which had 1 day at 24 knots ('strong breeze').



*The graphs shown are for weekly values for 2003 and the long term average for 1961-1990( ).
Statistics in the text are measured against the monthly Long Term Average (LTA) for 1971 to 2000.

Institutes supported by the Biotechnology and Biological Sciences Research Council

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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
ATCC	American Tissue Culture Collection
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
BSPP	British Society for Plant Pathology
BTG	British Technology Group
CAPS	Cleaved Amplified Polymorphic Sequence
CEC	Commission of the European Communities
CEL	Crop Evaluation Ltd
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
CRAFT	Co-operative Research Action for Technology
Defra	Department for Environment, Food and Rural Affairs
DfID	Department for International Development
EAPR	European Association for Potato Research
ECOGEN	Soil ecological and economic evaluation of genetically modified crops
ECRR	Edinburgh Centre for Rural Research
ECSA	European Chips and Snacks Association
EHF	Experimental Husbandry Farm
ELISA	Enzyme linked immunosorbent assay
EPICA	European Project for Ice Coring in Antarctica
EPPO	European Plant Protection Organisation
EPSRC	Engineering and Physical Sciences Research Council
ER	Endoplasmic Reticulum
ESTs	Expressed Sequence Tagged Sites
EUCARPIA	European Association for Plant Breeding Research
FF	Flexible Funding (SEERAD)
FLAIR	Food-Linked Agro-Industrial Research
FSA	Food Standards Agency
FSE	Farm Scale Evaluation
GC-MS	Gas Chromatograph-Mass Spectrometer
GFP	Green Fluorescent Protein
GILB	Global Initiative on Late Blight
GIUS	Glasshouse Investigational Unit for Scotland
GM	Genetically Modified
GMHT	Genetically Modified Herbicide Tolerant
HDC	Horticultural Development Council
H-GCA	Home-Grown Cereals Authority
HPLC	High Performance Liquid Chromatography
HRI	Hannah Research Institute
HRI	Horticultural Research International
ICARDA	International Center for Agricultural Research in Dry Areas
ICTV	International Committee for the Taxonomy of Viruses
IIP	Investors in People
IITA	International Institute of Tropical Agriculture
IMP	Individual Merit Promotion
IOBC	International Organisation for Biological Control
ISHS	International Society for Horticultural Science
ISPP	International Society for Plant Pathology
ITMI	International Triticeae Mapping Initiative
IVEM	Institute of Virology and Environmental Microbiology
LC-MS	Liquid Chromatograph-Mass Spectrometer
LEAF	Linking Environment and Farming
MLURI	Macaulay Land Use Research Institute (now the Macaulay Institute)
MRI	Moredun Research Institute
mRNA	messenger RNA
MRS	Mylnefield Research Services
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
PCN	Potato Cyst Nematode
PCR	Polymerase Chain Reaction
PD	Post-doctorate
PIC	Product Innovation Centre
PVRO	Plant Variety Rights Office
RACER	Reduced Application of Chemicals in European Raspberry Production
RAPD	Randomly Amplified Polymorphic DNA
RFLP	Restriction Fragment Length Polymorphism
RNAi	RNA interference
RRI	Rowett Research Institute
RSPB	Royal Society for the Protection of Birds
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
SNH	Scottish Natural Heritage
SNSA	Scottish Nuclear Stocks Association
SPD	Senior Post-doctorate
SSCR	Scottish Society for Crop Research
STS	Sequence Tagged Sites
UNDP	United Nations Development Programme
USA NSF	USA National Science Foundation
VIB	Flemish Institute of Biotechnology
WHO	World Health Organisation