REVIEW OF BBSRC-FUNDED RESEARCH RELEVANT TO CROP SCIENCE

A report for BBSRC Council APRIL 2004

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FOREWORD

Agriculture is changing fast under many influences that include social, political, economic, environmental and climatic factors. This is happening at a time of rapid advances in fundamental understanding of plant science, enabled by developments in molecular biology. It is therefore timely for BBSRC to review its research in crop science that underpins much of agricultural and horticultural production.

BBSRC Council established the crop science review panel in July 2003 to take a medium- to longterm (10-20 year) view of future crop science research in relation to current strengths and weaknesses and to recommend a strategy that would optimise the outputs from basic plant science research, including model systems, into crop science. It was intended that the strategy should take account of related programmes by other national and international funders in order to promote partnerships to ensure a coherent and productive framework for crop science research. The terms of reference and the membership of the panel are given in Annex 1.

For the purposes of the review, 'crop science' is defined as, 'science that provides knowledge and technology enabling effective exploitation of cultivated plants'. This encompasses crops grown for food, animal feed including pastures, as well as non-food uses such as bioproducts, biofuels and biomass production. It also encompasses biotic and abiotic factors that limit or reduce crop performance, including pests, pathogens and weeds, drought and salinity, as well as beneficial factors, such as growth promoting micro-organisms. pest, weed and disease control.

In preparing the report, the panel has sought a wide range of views from academia, research institutes, industry, government departments and non-government organisations, using a consultation document and questionnaire (Annex 2) sent to a large list of interested parties and publicised on the BBSRC website. We also arranged interviews with leading plant and crop science experts in the UK and overseas. These are listed in Annex 3 along with respondents to the questionnaire. The views expressed by respondents were used extensively in preparing this report and the principal messages from submissions are summarised in Annex 4. We also took account of relevant international developments and activities and drew on numerous recently-published reports that relate to plant and crop science (Annex 5).

Structure of the report

We begin in Chapter 1 with a strategic overview of crop science research that reflects national and international challenges, as well as scientific opportunities that have arisen from recent investment in plant science research. The overview looks at where UK crop science research ought to be by 2025. In Chapter 2, we review current national investment in plant and crop science, from which we identify current strengths and weaknesses of UK research in crop science. Chapter 3 then proposes scientific priorities for future research in crop science and Chapter 4 identifies the delivery mechanisms necessary to achieve these priorities. A list of abbreviations used in the report is given in Annex 6.

Acknowledgements

BBSRC and the panel wish to thank those who responded to the consultation exercise for the many carefully considered and informative comments submitted, and the other research funding bodies who helpfully provided information for this review.

EXECUTIVE SUMMARY

Strategic overview of crop science research

Scope Crop science research has a broad remit that lies on a spectrum from basic plant science through to sustainable agricultural systems. It includes crops grown for food, for animal feed including pastures, as well as for non-food uses including renewable bioproducts, biofuels and biomass production. Crop science research also addresses biotic and abiotic factors that limit or reduce crop performance, notably pests, pathogens, weeds, drought and salinity, as well as beneficial factors, such as growth-promoting micro-organisms. It includes suitability for cultivation, for processing, consumption and for industrial use.

The report begins with a strategic overview of crop science research in order to identify the likely national and international changes in demand that will occur during the next 20 years. The overview takes account of political, economic and environmental drivers for change together with future agricultural, industrial and scientific opportunities.

Changing demands The following demands for UK crop science emerged. The types of crops grown within the landscape will change as growers respond to changing food demand, climate change and increasing international competition particularly from an expanded EU. New diseases and pests are likely to arise. There will also be: continuing needs to reduce inputs in order to avoid pollution; increasing requirements to develop crops that link food with diet and health; greater emphasis and increasing demands for non-food crops; new demands to maintain stable output from agriculture under changing climate including extreme events. Flexibility will also be required in exploiting genomic, proteomic and metabolomic information that permits both transgenic and non-transgenic approaches, depending upon public and industrial acceptability.

Scientific opportunities Scientific opportunities for improving crop productivity during the next 20 years are likely to centre upon: exploitation of genome sequences and gene function of model plant, crop, pathogen and pest species to identify multiple, as well as single, gene targets for crop traits; continued rapid advances in physiological, epidemiological and population understanding of plants, pathogens and pests; developments in integrative biology and mathematical modelling to scale from sub-cellular dynamics to predict whole plant and population behaviour; development of new breeding strategies to exploit genomic information in order to manipulate multiple target genes for a wide range of traits.

Conclusion We conclude that there will be significant needs for novel crop science research that is central to BBSRC's mission and high-level strategic priorities in the promotion of sustainable agricultural systems, integrative biology, crop bioscience for industry and the healthy organism. Progress will depend not only on national investment but also on international coherence and cooperation.

Strengths and weaknesses of the current research

The current annual expenditure by BBSRC on plant and crop science research is approximately $\pounds 65m$, accounting for more than 50% of the non-industrial, national expenditure. Rigorous distinction between expenditure on crop compared with plant science is difficult and prone to bias but BBSRC expenditure on 'basic' and 'enabling' through to 'field and sustainable crop science' accounts for ~ $\pounds 30-\pounds 35m$ annually, with the rate of increase in expenditure over the past three years in crop science (~8%) lagging behind that for plant science (35%). Work on individual plant species is currently dominated by *Arabidopsis*. The responses to national and international consultation showed that the UK has internationally leading and competitive research on *Arabidopsis* and in

certain areas of crop science. Four major weaknesses in current UK crop science research are apparent.

- There is no coherent strategy for crop research.
- Investment in plant science is not yet impacting on strategic and applied crop science.
- Fragmentation of funding within and between major funders is weakening the scientific strategy.
- There is a shortage of suitably trained personnel.

Priorities for crop science research

Defining a strategy The report proposes a framework for a coherent strategy for crop science research, with clear targets and technological priorities linked to the development of crops that produce high-quality, safe products within economically and environmentally sustainable agricultural systems. The strategy should build on the investment in plant science and genomics, take account of international science and complement the strategies of other UK funders. It should also foster training and career development to ensure continuity of expertise.

Setting clear targets The targets include:

- improving quality with respect to the whole food chain, including human health and other benefits for consumers;
- drought tolerance and water-use efficiency;
- durable and environmentally sustainable strategies for the control of pests, pathogens and weeds; improving efficiency of resource use and minimising waste;
- broadening the range and number of crop species and varieties including novel crops and products for bioenergy, biopharmaceuticals and biopolymers.

Technological priorities Technological priorities include, amongst others:

- development of new strategies, informed by genetic and genomic information, to accelerate the breeding process;
- improvement and management of genomic, proteomic and metabolomic data and germplasm collections;
- maintaining a balance between GM and non-GM approaches, using appropriate technologies to solve practical problems subject to societal acceptability;
- understanding key processes that underpin plant breeding: heterosis, genome function in hybrids, meiotic recombination, apomixis;
- development of mathematical and experimental techniques for predictive modelling at a range of scales from sub-cellular to whole plant and population performance;
- revision of crop ideotypes to bridge genomic analysis with selection of crop traits for improved crop performance.

Balancing the crop portfolio We take as a starting point that BBSRC crop science research should focus on UK crops and their associated organisms, under changing environmental, climatic and economic pressures. This implies a gradual broadening of ecotypes. Given the generic nature of the target goals, and the need for international investment to make significant progress, we conclude that BBSRC crop science research should also contribute to complementary international activities in improving crop traits for the EU and the rest of the world. This should occur where there is scientific synergy, and economic or social benefit. The report also recommends that BBSRC should focus future investment within function genomics to identify important crop traits in wheat, brassicas, legumes, forage *Gramineae* and *Solanaceae*. BBSRC should develop a strategy for research on non-food uses of crops that fosters a flexible science base for current and future needs. BBSRC should also support genomic sequencing and gene functional analysis of pests and pathogens, ensuring that this is developed within a population genetic and epidemiological

framework to promote durable pest and disease control. Finally, while strongly supporting the maintenance of excellent research in plant science, the report recommends some re-balancing of the plant science research portfolio to place greater emphasis on the transfer of knowledge from plant to crop science.

Delivery mechanisms

Co-ordination and strategy The report introduces three recommendations to set up and maintain a co-ordinated strategy for crop science research, within BBSRC, without stifling creative research. First is the establishment of a high-level steering group, to oversee the implementation and co-ordination of the targets and priorities for crop science research, including co-ordination with other national and international funders. Second is the appointment of three crop co-ordinators, one for cereals and grasses, one for non-food uses of crops and one to cover brassicas, legumes and *Solanaceae*. The co-ordinators should be working scientists based in the community and would work with the proposed high-level steering group, in developing and co-ordinating cohesive programmes of work across the relevant institutes. Third is a revision of the current committee structure with the creation of a single committee in order to promote and focus responsive mode funding for crop science, plant and sustainable agriculture.

International co-ordination and co-operation The report recommends that BBSRC should take the lead in the development of international programmes and proposes some funding arrangements to foster this and to support large-scale collaborative projects with external matching funding.

Translation from model plants to crops The report recommends that BBSRC should make the transfer of knowledge between plant and crop science a high priority. This requires a catalyst to assist the change in culture and we recommend that BBSRC should increase the proportion of the basic plant science budget that addresses this priority. We also recommend an injection of additional funding for new research aimed at the specific crop science objectives listed under the strategic targets and technological priorities.

Public-good plant breeding The response to the consultation exercise identified a widely perceived need for public-good plant breeding, in order to address crops and traits not emphasised by multinational interests and to restore public confidence in plant breeding. We recommend that BBSRC should take the scientific initiative in establishing a national plant breeding initiative in partnership with other funders. The initiative should aim to provide improved germplasm and technology for the development of new varieties, thereby complementing and supporting, not competing with commercial companies.

Training and career development A supply of well-trained crop scientists with appropriate career development is crucial to the success of the report's proposals. Crop scientists must be able to bridge genomics and integrative biology with crop genetics and modern breeding technologies. We propose a set of solutions to achieve this, ranging from changes in Ph.D. training to the establishment of a targeted, high-profile, postdoctoral fellowship scheme and university-institute senior fellowships. These solutions are not unique to crop science and the recommendations have broad applicability.

Public perceptions Finally, the report commends BBSRC on its continuing role in educating public perception of science and proposes how this could be enhanced for crop science.

SUMMARY OF RECOMMENDATIONS

Priorities

Recommendation 1 The key crop targets and technological priorities set out in paragraphs 3.3 to 3.4 should be adopted by the BBSRC as the basis of its strategy for crop science research, with appropriate realignment in the priorities of BBSRC's research committees and institutes. Progress towards implementing these targets and priorities should be regularly monitored by Council (see also recommendation 9). (paragraph 3.4)

Recommendation 2 BBSRC should develop a research strategy to exploit genomic information in crops and in models for both non-GM and GM approaches to improving crop performance. (paragraph 3.5)

Recommendation 3 BBSRC should ensure the efficient collection and curation of genomic information, together with maintenance of germplasm, for major groups of crop plants (cereals and grasses; *Solanaceae*; legumes; brassicas; non-food crops), through liaison with Defra, SEERAD and international agencies, as appropriate. BBSRC should also adopt measures to ensure the crop science community is aware and makes use of the genomics facilities and germplasm collections that are available. (paragraph 3.7)

Recommendation 4 Council should adopt the principle that the BBSRC crop science portfolio, supported through both institute and university investment, should encompass research with application beyond the UK where there is scientific synergy and economic or social incentive. (paragraph 3.9)

Recommendation 5 BBSRC should focus future investment in functional genomics in the context of identifying important crop traits in wheat, brassica, legumes, forage *Gramineae*, and *Solanaceae*. Large-scale genome sequencing should only be undertaken through partnership with national and international collaborators and ensuring that sequence data are publicly available. (paragraph 3.19)

Recommendation 6 Taking the government-wide Non-Food Crops Strategy into account, BBSRC should develop a strategy for research on non-food uses of crops that fosters an appropriate science base to serve current and future producer and end-user requirements. (paragraph 3.20)

Recommendation 7 BBSRC should support genome sequencing and gene functional analysis of pests and pathogens and ensure that this is developed within a population genetic and epidemiological framework to promote durable pest and disease control. Initial organisms for sequencing and functional genomics should be selected from the following candidate organisms: *Mycosphaerella graminicola, Peronospora parasitica, Blumeria graminis* and *Aphis pisi.* (paragraph 3.27)

Recommendation 8 BBSRC should seek to re-balance its plant science research portfolio to place greater emphasis on crop science and to promote the transfer of knowledge from plant science to crop science by implementing recommendations 9 to 13. (paragraph 3.33)

Delivery mechanisms

Recommendation 9 Council should establish a high-level steering group, chaired by a member of Council, to maintain a strategic overview of the development of the BBSRC crop science research and training portfolio, including the implementation of recommendations 1 to 8. Council should also consider the need to establish co-ordinated programmes on specific crops or groups of crops. The steering group should ensure co-ordination within BBSRC so that the relevant institute programmes and the university grants portfolio develop in synergy with other national funders. (paragraph 4.11)

Recommendation 10 BBSRC should appoint co-ordinators for three areas of crop science, one for monocots, a second for non-food uses of crops, and the third for brassicas, legumes and *Solanaceae*, in order to develop and co-ordinate cohesive programmes of work across BBSRC institutes with the longer-term aim of integrating the work at BBSRC institutes, SEERAD-sponsored bodies and universities. (paragraph 4.15)

Recommendation 11 Council should revise the current committee structure with the aim of forming a single committee with responsibility for promoting and focusing responsive mode funding for crop science, plant science and sustainable agriculture. (paragraph 4.22)

Recommendation 12 Institute reporting procedures should clearly identify dedicated crop science projects that are distinct from other aspects of plant science and indicate the strategic importance of the project, the total funding of the project and the contribution made from CSG. (paragraph 4.24)

Recommendation 13 Council should:

- a) Seek to increase the proportion of the basic plant science budget that addresses the priority of knowledge transfer from plant to crop science whilst maintaining the current level of support for basic plant science;
- b) provide additional funding of £12m for new research aimed at the specific crop science objectives set out in paragraphs 3.3 to 3.4;
- c) ensure that there is flexibility in funding to support large-scale, collaborative projects with external matching funding up to £4m as well as recurrent funding for co-ordination, training and data management. (paragraph 4.30)

Recommendation 14 BBSRC should take the lead to establish a national plant breeding initiative, in partnership with other funders drawn from government, charities and the private sector, that would promote public-good plant breeding by establishing crop genetic improvement programmes with the aim of providing improved germplasm and technology for the development of new varieties. (paragraph 4.36)

Recommendation 15 BBSRC should seek to lead rather than respond in the development of international research programmes in crop science by strengthening relationships with INRA and DFID, among others, encouraging international networking and providing funds to facilitate international partnerships. (paragraph 4.40)

Recommendation 16 BBSRC should review its training programmes and career development for crop scientists by considering the introduction of targeted schemes for training and recruitment at senior, postdoctoral and postgraduate levels including international secondments. (paragraph 4.42)

Recommendation 17 BBSRC should seek to increase publicity for public-good plant breeding and to emphasise the role of genomically-informed but non-transgenic approaches to crop science research. (paragraph 4.45)

Chapter 1 Strategic overview of crop science research: where do we want to be by 2025?

Introduction

- 1.1 Crop science research has a broad remit that lies on a spectrum from basic plant science through to sustainable agricultural systems. Whereas research in plant science focuses on improving understanding of fundamental plant processes, crop science focuses on strategic and applied research that leads to efficient exploitation of cultivated crops within economically and environmentally sustainable agricultural systems.
- 1.2 Target crops include those that are grown for food, for animal feed including pastures, as well as for non-food uses such as renewable bioproducts, biofuels and biomass production.
- 1.3 Crop science research also addresses biotic and abiotic factors that limit or reduce crop performance, notably pests, pathogens and weeds, drought and salinity, as well as beneficial factors, such as growth promoting micro-organisms. It includes suitability for cultivation, for processing, consumption and for industrial use.
- 1.4 We list below some of the current and future changing demands for crop science in the UK over the next 20 years and show that the agricultural landscape is likely to change substantially by 2025. There is a long lead-in time to introduce, scale up, release and process new crops and new varieties of existing crops, so that changes in the underlying science have to be initiated now.

Drivers of change in a UK and international context

- 1.5 Agriculture is changing rapidly under many influences that include social, economic, environmental and climatic factors (listed below). This is happening at a time of rapid advances in fundamental understanding of plant science, enabled by advances in molecular biology, genomic and post-genomic science. The scales and rates of change are such that major shifts in cropping patterns and in crop productivity within the UK will be demanded during the next 20 years, necessitating investment and change in national crop science research.
- 1.6 **Increasing world food demand** The world demand for cereals is predicted to increase by 30% by 2020¹. This is driven by increasing population pressures with greater urbanisation, as well as improved standards of living, leading to a change in customer demand from coarse-grained cereals towards wheat. Two thirds of this increase is predicted to occur in developing countries but changes in import and export markets are likely to have a significant impact on EU production. The corresponding demand for animal products, with improving incomes in SE Asia, is predicted to increase by 50% with significant demands for animal feed crops¹. Most of the increase in production will come from improved yield rather than larger growing areas, although there will be pressure in some regions to exploit marginal land for agriculture. To achieve and maintain the necessary improvements in yield, agriculture will need to overcome major challenges such as drought, salinity, soil quality, biotic stress and loss from pests, pathogens and weeds. These challenges will be addressed through scientific and technological advances that are common to crops for developed and developing countries.

¹ Rosegrant, M. W., Paisner, M. S., Meijer, S. & Witcover, J. (2001) *Global Food Projections to 2020: Emerging Trends and Alternative Futures.* Washington: International Food Policy Research Institute.

- 1.7 *Climate change* The extent of climate change over the next 20 years and its impact are difficult to predict but it is essential to put research in place now that will be needed in the longer term. Current trends² suggest not only a long-term increase in mean temperatures but also higher frequencies of extreme events such as flooding or drought. Such events will impose demands for crops with improved resistance to summer drought, winter water-logging and with different control of flowering, as well as resistance to pests and diseases that are currently unimportant in the UK. Climate change will impose new demands on UK agriculture not only by direct impact through changes in seasonality, temperature and rainfall patterns but indirectly through the large-scale sub-continental changes in cropping patterns within world agriculture.
- 1.8 *EU-driven change and international trade* Enlargement of the EU to include several Eastern European states, together with changes in subsidies through reform of the Common Agricultural Policy and compliance with directives on agricultural sustainability, will intensify competition on UK agriculture and place more emphasis on treating farming systems as entire ecosystems rather than purely as food production units. Three UK crops wheat, oilseed rape and sugar beet are especially vulnerable to greater competition. Although the UK has been highly successful at improving wheat quality and the production of oilseed rape, several of the new EU accession states may have more appropriate climates for bread-making wheat and oilseeds and lower production costs. Reduced trade tariffs and barriers could eliminate sugar-beet production in the UK and affect other crops such as wheat, oats, barley and grain legumes for animal feed. The competitiveness of UK agriculture will also be influenced by shifts in the balance of global trade, whether driven by increasing demands for world food or by climate change.
- 1.9 *Non-food crops* The development of new non-food crops is set to play a critical role in the UK economy over the next 20 years, driven by the demands for renewable energy resources, diminishing stocks of oil and the socio-economic attractions for farmers and producers to develop new markets. There is a need to find alternative sources of industrial feedstocks currently derived from petrochemicals because of the inevitable decline in the supply of fossil fuels. Oil reserves are estimated to run out in 35-65 years and biofuels and bioproducts have been estimated to achieve a potential 10% and 18% of their respective markets by 2010³. The background, scientific challenges and opportunities for the application of nonfood uses of crops are comprehensively set out in a recent report by the Institute of Innovation Research⁴.
- 1.10 **Changing consumer attitudes and public-good plant breeding** The future direction of agribusiness worldwide will be driven not only by the impact of shifts in global trade associated with production costs, subsidies, environmental factors and regulatory changes but also consumers' desires in the developed world for safer, higher quality and more nutritious foods. The agglomeration of multinational agribusinesses and the associated withdrawal of leading crop and plant biotechnology research from the UK, however, leaves

² Watson, R.T. *et al.* (2001). Climate change 2001:Synthesis report: a contribution of working groups I,II,III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, University Press.

See also King, D.A. (2004) Climate change science: adapt, mitigate or ignore? *Science* 303, 176-177.

³ Anon. (2002) Roadmap for Biomass Technologies in the United States: Biomass Research and Development Technical Advisory Committee.

⁴ Institute of Innovation Research (2004). Prospecting Bioscience for the Future of Non-food Uses of Crops; report commissioned on behalf of the Government Industry Forum on Non-Food Uses of Crops

a void in long-term research directed at improving crop varieties for UK agriculture. This, together with competing demands from supermarkets and wider consumer requirements for environmentally sustainable food production, suggest that public-good plant breeding is under-resourced in the UK^5 .

1.11 *Genetically modified crops* The term genetically modified (GM) crop is often used loosely and imprecisely. Here we define GM crops as those in which the transfer of one or more genes has been accomplished by recombinant DNA technology. Public acceptability of GM crops is still uncertain in the EU notwithstanding recent reports that advocate judicious, case-by-case use of GM crops⁶. Cultivation of GM crops is widespread in the USA, Canada, and Argentina and is expected to become so in China and India. In the future, however, transfer of single genes is likely to become the exception, with greater attention being given to the identification, manipulation and selection of multiple genes that control complex agronomic traits. Progress here will come from the development of modern breeding strategies that exploit genomics⁷ data in breeding programmes. It may or may not involve transfer of genes between genera but it will certainly require improved genomic information. Progress will also come from a better understanding of the process of secondary metabolite formation to permit increased yields of nutritionally improved or industrially useful plant compounds.

Agricultural, horticultural, industrial and environmental opportunities

- 1.12 While the political, economic, social and environmental factors listed above will impose change, they also promote opportunities for science-driven change in crops. Some of the principal opportunities are listed below.
- 1.13 *Improving nutritional and processing quality* There is a pressing need to enhance the nutritional quality of food crops both in terms of the quality of traditional sources of food in developing countries and also to meet consumer demands in the developed world. In the UK the primary emphasis should be targeting major health problems such as coronary heart disease, obesity, diabetes and cancer. Important contributions can be expected from enhancing the nutritional properties of major crops, including vegetables, through cross-disciplinary research in collaboration with nutritionists and medical scientists. Concomitant progress is also anticipated in the redesign of food crops for enhanced processing quality to meet improving nutritional standards.
- 1.14 *Minimising crop losses* Although there have been marked successes, pathogens and pests continue to cause significant crop loss, while drought and salinity remain serious problems. The effectiveness of genetic and chemical methods of control is often short-lived, while biological control is still largely empirical. Advances in comparative genomics, together with greater understanding of quantitative trait loci, offer opportunities to develop durable methods of pest and disease control as well as improved crop responses to abiotic stress.
- 1.15 *Improving efficiency and reducing waste* Efficiency can be improved, by increasing output and by decreasing input as well as by improving quality and uniformity in relation to market requirements. The drive towards more sustainable and diverse farming systems whilst maintaining profitability will put greater emphasis on reducing inputs and minimising

⁵ Defra (2002) 'The Role of Future Public Research Investment in the Genetic Improvement of UK Grown Crops

⁶ Anon. (1999) Genetically modified crops: the ethical and social issues. Nuffield Council on Bioethics.

Anon. (2003) Prime Minister's Strategy Unit Report (July 2003)

⁷ Throughout the report the term genomics encompasses metabolomics, proteomics, transcriptomics as well as the analysis of gene sequences.

wastage than has occurred in the past 50 years. This will require significant redesign of crops and the development of new cultivars. Other opportunities include bioremediation of soil by using plants to absorb and sequester heavy metals; development of crops to exploit specific soils; improving the quality of cereal grain and forage crops to improve animal nutrition and reduce nitrogen excretion by poultry and other livestock.

- 1.16 *Novel non-food crops for biofuels, biopharmaceuticals, biopolymers and speciality chemicals* The development of non-food crops as renewable industrial feedstocks has been hampered by the availability of cheaper raw materials from traditional sources such as petrochemicals that can be processed by proven technology. This will change as petrochemicals become more expensive and demands increase for renewable resources. The key challenge is to develop more cost effective raw materials by tailoring existing crops and developing new crops to produce ingredients that industry wants, can afford and that meet consumers' needs. Future opportunities include:
 - high volume uses such as:
 - *structural and packaging materials* based on starch and protein polymers that are biodegradable, compatible with living cells and tissues and without negative impacts on the environment;
 - bioenergy: ligno-cellulose for heat, power and advanced fermentation to ethanol; starch or oilseed crops for liquid biofuels such as bioethanol or biodiesel. Bioethanol may be an opportunity for the UK if the technology for the degradation of waste crop material becomes more competitive;
 - *industrial fibres* for insulation, packaging and construction materials, including flax, hemp and jute as composite materials for the automotive industry
 - low volume, high value compounds such as:
 - biopharmaceuticals including secondary products, recombinant vaccines and antibodies in crop plants. Reliable mechanisms to minimise unwanted gene flow to food crops or wild plants will be essential. The IOIR report⁸ concludes that it is unlikely that the open field cultivation of biopharmaceuticals adopted in the US would be applicable in Europe and that controlled agronomy under glass would offer better commercial opportunities.
 - speciality chemicals such as:
 - *adhesives, crop protection chemicals, personal care products*: soaps and detergents;
 - *polymers and plastics*, as well as dyes, paints and pigments;
 - *industrial oils* and lubricants.
- 1.17 The realisation of these opportunities will depend not only on scientific advance but also most importantly on public acceptability, potential impact on the environment and economic viability. The accurate identification of markets and flexibility in exploiting underlying science will be of paramount importance.

Scientific opportunities

1.18 There have been rapid advances in molecular understanding of plant science, pathogen and pest biology during the past decade, much of this funded by BBSRC. Highlights include the

⁸ Institute of Innovation Research (2004). Prospecting Bioscience for the Future of Non-food uses of Crops; report commissioned on behalf of the Government Industry Forum on Non-Food Uses of Crops

cloning of resistance genes, and the identification of genes controlling flowering time, vernalisation and plant architecture. Others include improved understanding of signal transduction and of semiochemistry in relation to beneficial insect and pest behaviour as well as modification of storage products by better understanding of the synthesis of starch, oil and protein. There have also been major advances in the availability of genomic information for model species that is now allowing high-throughput functional genomics to determine gene function in model and crop plants. The current challenge is to establish how genes and their products interact in the plant as a whole and in crop plants in particular.

- 1.19 The genome sequences are available for a monocot crop, rice, as well as *Arabidopsis thaliana* and sequences will become available for maize, poplar, *Medicago truncatula* and, potentially, for *Brassica rapa*. Fifteen fungal genome sequences, including those of important pathogenic species (*Magnaporthe grisea, Ustilago maydis,* and *Fusarium graminearum*, now in draft form), are expected to be generated by 2005⁹.
- 1.20 Scientific opportunities for improving crop productivity during the next 20 years centre on:
 - continued rapid advances in molecular, physiological and epidemiological understanding of plants, pathogens and pests;
 - integrative biology and mathematical modelling to scale from sub-cellular dynamics to predict whole plant and population behaviour;
 - exploitation of genome sequences of model plant, crop, pathogen and pest species to identify multiple, as well as single, gene targets for crop traits;
 - development of new breeding strategies to exploit genomic information in order to manipulate multiple target genes for a wide range of traits.
- 1.21 Amongst these, significant progress is already being made in:
 - genomics;
 - transformation technology;
 - identification and manipulation of single gene targets.
- 1.22 Future progress will demand additional scientific developments in:
 - proteomics and metabolomics in order to identify gene function and establish protein and metabolite interactions that influence economically and ecologically important crop traits;
 - identification and manipulation of multiple gene targets, involving quantitative trait loci and marker-assisted breeding;
 - pharmaceutical, protein-based production systems in crop plants for medical applications;
 - biomathematics for integrative biology and bioinformatics for analysis of functional genomic data;
 - data management for efficient exploitation of germplasm collections.
- 1.23 On the basis of current developments, crop science can be anticipated to push in a number of general directions including:

⁹American Phytopathological Society (2003) Microbial genomic sequencing: perspectives of the American Phytopathological Society. http://www.apsnet.org/media/ps/MicrobialGenomicsSeqFinal03.pdf accessed 06/02/04

- continued genome sequencing in crop plants such as wheat, maize, other cereals, *Brassica*, tomato, *Medicago truncatula*, soybean and pathogens as major activities, accompanied by continuing development and exploitation of functional genomics resources;
- exploiting information from *Arabidopsis* as the dominant model for higher plants including a decreasing dominance of the reductionist approach and an increasing emphasis on integrative biology and systems approaches;
- greater attention to selected genomic analysis and identification of gene function in crop plants;
- development of high-throughput technologies for gene functional analysis in crop pathogens leading to more detailed understanding of crop diseases and resistance mechanisms;
- developing a greater understanding of gene function at the population and ecological levels as well as cellular and organismal levels using advanced methods of mathematical modelling;
- developing a greater understanding of the interactions between crops and populations of beneficial and problem species; and between cropping systems, at all levels and all scales, with the general environment through an integrated, multidisciplinary approach;
- improving crop quality and linking quality attributes with processing requirements across the whole supply chain.

Conclusions: setting a strategy for UK crop science

- 1.24 Combining the predictions from national and international drivers with agricultural, environmental, industrial and scientific opportunities, the following demands for UK crop science are evident.
 - There are likely to be demands for profound changes in the crop mosaic within the landscape.
 - New diseases and pests are likely to arise.
 - There will be continuing demands to reduce inputs in order to reduce pollution.
 - There will be increasing demands for crops that link food, diet and health.
 - There will be greater emphasis on and increasing demands for non-food crops.
 - There will be new demands for maintaining stable output from agriculture under changing climate including extreme events.
 - Flexibility will be required in exploiting genomic, proteomic and metabolomic information that permits both transgenic and non-transgenic approaches, depending on public and industrial acceptability.
- 1.25 We conclude, therefore, that there will be a need for novel crop science research that is central to BBSRC's mission and high-level strategic priorities in the promotion of sustainable agricultural systems, integrative biology, crop bioscience for industry and the healthy organism. Progress will depend not only on national investment but also on international coherence and co-operation.

Chapter 2 Current BBSRC-funded research relevant to crop science

Introduction

2.1 We begin by analysing the total BBSRC expenditure and the balance between crop and plant science, as well as expenditure on individual species in university and institute projects. We then consider the distribution of activity amongst the various institutes. BBSRC expenditure is set in the context of the other UK funders. Finally, drawing on the results of the consultation exercise, interviews and other background information (see Annexes 4-6), we summarise the major strengths and weaknesses of UK crop science.

BBSRC Funding

- 2.2 Table 1 summarises BBSRC funding for research on crop plants and other plant science from 2000/01 until 2002/03. Combined BBSRC spending on plant and crop science has increased by some 18.5% during this period, compared with a 22% increase in BBSRC's gross expenditure. Much of this increase occurs under 'plant science' (35%), compared with 'crop science' (8%), with greater increase in research grants than in the Core Strategic Grant (CSG) to BBSRC institutes.
- 2.3 Rigorous distinction between expenditure on crop science compared with plant science is difficult and prone to bias because it relies on analysis of project titles and abstracts within the BBSRC database. We began by classifying as 'crop science' any project that made reference in the abstract to explicit investigation of a crop plant, pathogen, pest, weed or post-harvest product. All other work on model species was classified as 'plant science'. This suggests that crop science accounts for 56-61% of the total expenditure (Table 1). However, these overall figures do not differentiate between basic plant science undertaken on crop species and work on the crop *per se* and the reality of the balance of funding towards crop science was challenged by numerous respondents to the questionnaire.
- 2.4 The crop science component (grants and CSG projects for 2002/03) was further subdivided into four categories encompassing a spectrum from basic plant science undertaken on crop plants to field and sustainable crop science (Table 2). The analysis showed that work on basic and enabling crop science accounted for £27.2m (i.e. 45% of the total expenditure of plants and crop science in 2002/03, excluding studentships) with £2.9m (~5%) on field and sustainable crop science and £4.4m (~7%) on basic plant science involving crop plants. We note, of course, that projects on model species (classified as plant science) will have corresponding applications to crop science.

	Research funded per financial year (£k)			
Category	2000/01	2001/02	2002/03	% Change
Crop Plants:				since 00/01
Grants	£11,141	£12,693	£13,983	25.5%
CSG projects	£20,737	£20,555	£20,555	-0.9%
Studentships	£1,705	£1,723	£1,660	-2.6%
Total Crop Plants	£33,582	£34,970	£36,199	7.8%
Plant Science:				
Grants	£15,210	£18,095	£21,427	40.9%
CSG projects	£3,803	£4,567	£5,028	32.2%
Studentships	£2,133	£2,279	£2,186	2.5%
Total Plant Science	£21,146	£24,940	£28,640	35.4%
Grand Total	£54,729	£59,910	£64,839	18.5%

Table 1: Summary of BBSRC funding for crop science and plant science

Table 2: Classification of BBSRC crop science research Spend (£k) for 2002/03 with (% change since 2000/01)

Category	Grants	CSG Projects	Total
Basic plant science		TTOJECIS	
Basic plant science often focused on model	f3 373	f1 040	£4.413
species with brief analysis of related	(32.7%)	(-13.7%)	(17.8%)
behaviour in crop: still far removed from	(32.170)	(15.770)	(17.070)
impacting on crop production			
Basic gron science			
Includes a broad range from exploratory	£6.447	£6.9/3	£13 300
studies of components of a chain to trait-	(14, 3%)	(-2, 2%)	(15,7%)
driven analyses of drought resistance	(44.370)	(-2.270)	(13.770)
processing quality: still some way from			
impacting on crop production pest and			
disease control Also includes some general			
mapping			
Enabling aron saionea			
Aroos of onebling science with high	£2 242	£11 505	£12.847
Aleas of eliability science with high	(11.20%)	(2, 10)	(0.40)
on cron science of breading strategies	(-11.2%)	(3.1%)	(0.4%)
Also includes speculative projects with			
Also includes speculative projects with potential high impact but lower probability			
of success			
Di success.			
Field and sustainable crop science	C1 0 0 1	61.077	CO 000
Direct relevance to crop science usually	$t_{1,\delta_{21}}$	t1,00/	$t_{2,888}$
involving significant field experimentation:	(21.9%)	(-16.0%)	(4.5%)
encompasses research on sustainability.	012.002	000 555	024 520
Grand Total	£13,983	£20,555	£34,538
	(25.5%)	(-0.9%)	(8.3%)

- 2.5 The distinction between model and crop plant species is further shown in Table 3. BBSRC research on individual plant species is dominated by projects involving *Arabidopsis*, which accounted for almost 30% of the funding in 2002/03. Of the major crop species, funding for wheat amounted to around 10% of the total. CSG projects show less bias towards *Arabidopsis* than do research grants or studentships.
- 2.6 We conclude from Tables 1 and 2 that clear distinction of funded BBSRC science into plant and crop science is difficult but that expenditure on crop science accounts for 45 to 60% of total expenditure on plant and crop science, depending upon the nature of the definition of crop science. We also conclude that the rate of increase in expenditure over the past three years in crop science has been less than for plant science and that work on individual plant species is currently dominated by *Arabidopsis* (Table 3). At the current stage of development of the technologies, this is not unexpected and indeed is necessary. Over the next 20 years there will be a shift to work on more complex organisms, including crop plants, and BBSRC must position itself to drive this.

	Research Grants		CSG J	Studentships	
Species	Spend	No. of grants	Spend	No. of projects	No. of projects
Arabidopsis	£13,127	238	£4,763	63	45
Wheat	£2,629	40	£3,708	61	26
Brassica	£1,648	20	£1,757	15	3
Tomato	£1,185	19	£752	5	6
Potato	£818	19	£818	9	7
Maize	£987	18	£953	13	5
Legume (excl. pea)	£879	16	£1,948	18	5
Barley	£700	14	£1,009	21	9
Fruit	£629	14	£673	6	4
Grass	£616	11	£2,557	18	2
Rice	£537	11	£392	16	3
Pea	£517	10	£837	25	1
Oat	£487	10	£613	7	1
Oilseed/rape	£692	9	£860	16	4
Cereal (other)	£284	7	£1,472	17	8
Beet	£248	4	£270	3	5
Sunflower	£117	2	£105	1	0
Lettuce	£61	1	£0	0	1

Table 3: BBSRC spend (£k) by species (2002/03)*

*Projects active in 2002/03, including work on relevant pests and pathogens. Note that projects involving more than one species may be counted in more than one category.

SEEKAD institutes (snapshot for 2002/03)								
Торіс	JIC	RRes	IGER	IFR	SRI	HRI	SCRI	Total
Genetics and crop	£2,630	£627	£1,604			£156	£2,118	£7,135
improvement								
Metabolism ^a	£1,025	£1,921	£414			£238	£1,609	£5,208
Chemistry ^b	£689		£562	£830			£1,000	£3,082
Plant cell biology and	£2,470	£897	£127			£1,317	£576	£5,386
development								
Plant disease, plant	£1,406	£1,271	£307			£1,026	£1,402	£5,412
microbe-interactions								
Plant-pest interactions	£100	£2,188				£212	£666	£3,165
Systems, environment		£365	£138		£93		£487	£1,083
Soils		£1,042	£393		£568	£216	£971	£3,191
Mathematics and modelling	£57	£351			£343		£326	£1,076
Total	£8,376	£8,662	£3,545	£830	£1,004	£3,166	£9,155	£34,738

Table 4: Cost (£k) of research programmes relevant to crop science across BBSRC and SEERAD institutes (snapshot for 2002/03)

^a including nutrients, source-sink relations, metabolite signalling, gene expression

^b including analysis and modification of the composition of plant and food materials

Major institute programmes

2.7 Table 4 illustrates the range and cost of plant and crop related research at the relevant BBSRC-sponsored institutes and the Scottish Crop Research Institute (SCRI), across a number of topics.

Other main funders of research on plant science and crop science

- 2.8 Table 5 summarises the funding for crop and plant science research in the UK provided by the major funders. Figures for EU funding and research spend by industry within the UK are not included since these are not readily available. BBSRC funding accounts for around half of the total in Table 5. Defra and SEERAD support accounts for 21% and 13% respectively.
- 2.9 Of the £26.4m expenditure on crop science by Defra in 2002/03 (see Table 5), £5.5m and £11.7m was allocated to horticultural and arable crop science respectively. Linked to Defra's wider programme of livestock research, £1.5m was spent on forage crops, mainly on the genetic improvement of forage grass and clover. £1.8m was spent on research to support the non-food uses of crops and about £0.6m on crop science in support of organic farming. Defra currently contributes £0.4m p.a. to the maintenance of plant genetic resources. Direct regulatory support accounts for about £4.9m through crop science supporting pesticide safety (ca £2.0m), the regulation of GMOs (ca £2.0m), support of the Plant Health Service largely through biological research on exotic pests and diseases (£0.6m) and support of the regulation of plant varieties and seeds (£0.3m).
- 2.10 Of the SEERAD total of £15m for plant and crop science research, approximately £4m supports research on crop improvement (germplasm evaluation, crop genetics and plant genomics) principally on potato, barley and soft fruit; about £3m covers research on plant molecular biology and cell biology, that is intended to inform advances in crop science. Over £3m is spent on crop pathology, with emphasis on the pests and pathogens of potato. A significant part of SEERAD's plant genomics effort has been funded through relevant BBSRC initiatives. Most of the plant and crop science work is undertaken by the Scottish

Crop Research Institute, with additional crop science at the Scottish Agricultural College and plant science at the Royal Botanic Gardens, Edinburgh.

	Research funded per financial year (£k)			
Funder*	2000/01	2001/02	2002/03	
BBSRC	£54,729	£59,910	£64,839	
Defra	£30,161	£28,655	£26,349	
SEERAD	£12,912	£14,215	£15,460	
DARDNI	£2,252	£2,447	£2,350	
NERC	£6,241	£9,536	£9,313	
HGCA	£5,590	£5,161	£4,872	
Gatsby	£3,507	£1,787	£4,206	
HDC^{10}	£1,958	£750	£2,086	
BPC	£960	£1,041	£941	
Grand Total	£118,310	£123,504	£123,504	

Table 5: Funding of UK research in crop and plant science

*see Annex 6 for abbreviations

Strengths and weaknesses of UK research on crop science

- 2.11 Table 6 summarises the strengths and weaknesses of the research base relevant to crop science in the UK, drawing on the responses to the questionnaire (Annex 2) and interviews with leading international experts (Annex 3). The UK has considerable strengths in plant science and crop genetics including internationally leading and competitive *Arabidopsis* research. At present, however, the advances made in basic plant science are not yet having a significant impact on strategic and applied research in crop science (see Annex 4). There is a need for greater emphasis on crop improvement research to be carried out alongside, and feeding from basic plant science research programmes. BBSRC plant science research has tended to favour reductive work at the expense of studies at the whole organism and systems level. This concurs with similar observations in the Sustainable Agriculture Report¹¹.
- 2.12 RRes, IGER, JIC, SCRI and HRI¹² are major centres of excellence with critical mass and excellent facilities and resources including long-term field studies at RRes and IGER. However, some research institutes are perceived as becoming more like universities with a switch in balance away from long-term strategic and applied research towards basic science, characterised by short-term projects. This tendency has increased in BBSRC-sponsored institutes through access to responsive mode funding that was previously available only to university researchers.

¹⁰ HDC financial year of six months for 2001/02

¹¹ Review of BBSRC-Funded Research Relevant to Sustainable Agriculture (2002)

¹² HRI is now incorporated into the University of Warwick as Warwick HRI. Expertise in crop science will be maintained with BBSRC funding switching from CSG to responsive mode.

	itesses of crop science research in the OK
STRENGTHS	WEAKNESSES
Substantial commitment by BBSRC, Defra	Lack of co-ordination between different funders
and SEERAD to wide-ranging research	for crop-related research programmes
programmes	
World-class, creative, highly skilled plant	Currently no coherent overarching strategy for
genomics	crop research.
Well developed resources and facilities for	Crop science is seeking to feed from rather than
Arabidopsis	set the strategy for underpinning plant science
	research. Reductionist approach of plant science,
Critical mass of expertise and resources at	The strategic role of institutes in pursuing long-
RRes. JIC. HRL IGER and SCRI	term research is changing by access to responsive
	mode with short-term goals.
Genomics resources established for some	Sequence data and resources for crop plants and
crops. Some integration with relevant	pathogens require further development; no
international sequencing programmes	continuity of support
Successful, strong tradition of crop genetics	Lack of integration with basic plant science; lack
	of public sector plant breeding; lack of market
	pull from UK-based agribusiness
Long-term field studies at RRes and IGER	Insufficient emphasis on integrative and systems
with programmes on ecological interactions in	studies
Well share to include the second of the second to include the second sec	De la cel completione en este este este este este este este
well characterised sources of diversity in	Reduced emphasis on crop science at universities
	Charters of suitably trained researchers in some
	areas: poor career opportunities for crop scientists
Crop science complemented by expertise in	Biomathematics under-exploited lack of
soil science, plant pathology, entomology and	emphasis on importance of downstream
biomathematics	processing

Table (Cur

- 2.13 BBSRC initiatives such as Investigating Gene Function (IGF) and Exploiting Genomics have established genomics resources that are available to the relevant crop science communities, as well as for Arabidopsis research.
- 2.14 The principal UK funders of crop-related research, BBSRC, Defra and SEERAD, together provide substantial support amounting to around £107m annually. Many respondents drew attention, however, to the fragmentation of funding with a consequent lack of co-ordination for research in plant and crop science. The problem of co-ordination applies not only amongst the various funders but also within BBSRC funding, in that core-funded programmes at institutes are not well coordinated with responsive mode funding and initiatives (see paragraphs 4.1, 4.9).

2.15 Historically, the UK has maintained strong research expertise in areas that complement crop science such as entomology, nematology, plant pathology, weed biology, biomathematics and soil science but some of these areas, notably field-based genetics and germplasm improvement, field-based pathology, nematology and weed science, have become less prominent and do not currently have the capacity to bridge plant and crop science. There is considerable potential for mathematical techniques to become a major strength and make a significant contribution towards understanding complex systems. However, predictive and integrative modelling is currently under-utilised.

Conclusions

- 2.16 We conclude that:
 - there is considerable excellence in UK plant science research and in areas of crop science research funded by BBSRC;
 - there are four major weaknesses in current crop science research:
 - the absence of a coherent strategy;
 - investment in plant science not yet impacting on strategic and applied crop science;
 - fragmentation of funding;
 - shortage of trained personnel.

Chapter 3 Priorities for crop science research

Introduction

3.1 Given the weaknesses listed in Chapter 2 we first identify what we consider would be a coherent strategy for crop science research. We identify the scientific priorities for crop science research in paragraphs 3.3 to 3.27. The mechanisms by which these priorities could be delivered are set out in Chapter 4. In this chapter we go on to consider the balance of the crop research portfolio and the relationship between basic plant science and crop science.

Defining a coherent strategy for crop science research

- 3.2 A coherent strategy for BBSRC crop science research should:
 - have clear targets aligned to development of crops that produce high-quality, safe products within economically and environmentally sustainable agricultural systems;
 - build on investment in plant science and genomics;
 - take account of international science;
 - complement and underpin strategies of other UK funders;
 - foster training and development to ensure continuity of expert personnel.

Developing scientific research priorities for BBSRC

Setting clear targets

- 3.3 We identify the following targets:
 - improving quality with respect to the whole food chain, including human health and other benefits for consumers;
 - drought tolerance and water-use efficiency;
 - durable resistance and/or control strategies for pests and pathogens and control of weeds while protecting biodiversity in the wider environment;
 - improving efficiency of resource use and minimising waste through:
 - lower input, including nutrient efficiency and lower residue systems;
 - increasing yield and quality including seed composition;
 - promoting greater crop adaptability to fluctuations in environmental conditions;
 - extension of growing season;
 - broadening the range and number of crop species/varieties including novel crops and products for:
 - bioenergy;
 - biopharmaceuticals and nutraceuticals;
 - biopolymers.

Technological priorities

- 3.4 We identify the following technological priorities:
 - develop new strategies informed by genetic and genomic information to accelerate the breeding process;
 - improve the management, maintenance and utility of national resources for:
 - genomic, proteomic and metabolomic data;
 - germplasm collections;
 - genomic resources such as BAC libraries;
 - maintain and balance GM and non-GM approaches, using appropriate technologies to solve practical problems subject to societal acceptability (including mutagenesis and identification of induced and natural mutations);
 - understand key processes underpinning plant breeding: heterosis, genome function in hybrids, meiotic recombination, apomixis;
 - develop techniques for predictive modelling:
 - to scale up from sub-cellular to whole plant functioning;
 - to predict crop (i.e. population) performance;
 - to assess impacts of change in crop performance on sustainability;
 - review and revise crop ideotypes to bridge genomic analysis with selection of crop traits for improved crop performance.

Recommendation 1: The key crop targets and technological priorities set out in paragraphs 3.3 to 3.4 should be adopted by the BBSRC as the basis of its strategy for crop science research, with appropriate realignment in the priorities of BBSRC's research committees and institutes. Progress towards implementing these targets and priorities should be regularly monitored by Council (see also recommendation 9).

3.5 We highlight two further issues concerning technological priorities. First is the need to identify and generate new sources of variation for important traits and to strengthen the science underpinning the development of non-GM approaches to crop improvement such as the identification of allelic variants associated with improved function, introgression of chromosomal elements (or individual genes) from related species and resynthesis of polyploid crops. Transgenic plants involving gene transfer between species are not a prerequisite for exploiting genomics but do provide a useful tool in understanding gene function.

Recommendation 2: BBSRC should develop a research strategy to exploit genomic information in crops and in models for both non-GM and GM approaches to improving crop performance.

3.6 The second issue relates to management and access to data from genomics facilities. Data are accumulating at an unprecedented rate. These must be carefully managed in order to optimise the value of the investment and to prevent unnecessary duplication of effort. It is also important that appropriately annotated genomic data are linked with germplasm collections.

3.7 We are not convinced from our consultation exercise that crop scientists have yet gained adequate access to genomics facilities, and this could represent a bottleneck for the exploitation of genomics in crop plants (see paragraph 2.11). There is a need to educate the wider crop science community about the availability of genomics facilities through publicising the technology that is available and by demonstration and training. Secondments to expert centres should be considered. In addition, if genomic facilities are to be efficiently exploited, it is vital that expert technologists are maintained to run high-throughput equipment.

Recommendation 3: BBSRC should ensure the efficient collection and curation of genomic information, together with maintenance of germplasm, for major groups of crop plants (cereals and grasses; *Solanaceae*; legumes; brassicas; non-food crops), through liaison with Defra, SEERAD and international agencies, as appropriate. BBSRC should also adopt measures to ensure the crop science community is aware and makes use of the genomics facilities and germplasm collections that are available.

Balancing the crop portfolio

- 3.8 The research portfolio should include not only the crops upon which most work ought to be focused but also the associated pests, pathogens, weeds and beneficial organisms. It is not appropriate to produce an exhaustive list. Here we focus on the key principles and main types.
- 3.9 We take as a starting point that BBSRC crop science research should focus on UK crops and their associated organisms, under changing environmental, climatic and economic pressures. This implies a gradual broadening of ecotypes. Given the generic nature of the target goals, and the need for international investment to make significant progress, we conclude that BBSRC crop science research also has a role to play in improving crop traits for the EU and the rest of the world, when there is scientific synergy and economic or social incentive. An obvious example is selection for drought tolerance in wheat. Work on traits for non-temperate crops would be appropriate when there is at least matching funding or there are common goals in UK crops, such as drought tolerance or efficiency of water usage. The aim should be to contribute to a coherent programme within an international framework by complementing international activities, thereby maximising the benefit of UK and international R&D investment.

Recommendation 4: Council should adopt the principle that the BBSRC crop science portfolio, supported through both institute and university investment, should encompass research with application beyond the UK where there is scientific synergy and economic or social incentive.

3.10 Within this context we consider that the research portfolio should include four principal elements: crop types, models plants for functional genomics, non-food crops, and specific pests and pathogens.

Main crop types

3.11 Research programmes should take advantage of synergy with basic, strategic and applied research undertaken by SEERAD, Defra and complementary EU organisations. We

encourage research on a broad range of crop species to continue but expect the main focus to be on the following crops for food and animal feed:

- Small grain cereals (wheat, barley and oats)
- Oilseeds
- Forage crops
- Potatoes
- Legumes
- Horticultural brassicas

Model plants for functional genomics

- 3.12 We accept the rationale of capitalising on model species (rice, *Arabidopsis, Medicago*) for fundamental studies of plants. We note the strong probability that the genomes of all major crop species will be sequenced within 20 years and conclude that sequencing of crop species *per se* will not be a major obstacle to progress. However, sequence annotation is a potential bottleneck for informed use of model plants to identify crop traits. Without adequately annotated sequence information, crop science will remain in the pre-genomic era. Crop science must therefore actively set the agenda for work on model crops. We consider below some targets for selective genome sequencing for major crops.
- 3.13 *Cereals* Rice provides a good genomic model for all cereals and is ideal for generic science on such characteristics as tillering and floral development. Genomic and genetic resources for rice are becoming available to UK scientists from public and private sector efforts worldwide. Rice, however, requires specialised growth facilities and research is costly in the UK. Therefore, establishing a major UK-based rice programme would not be appropriate but it will be important to ensure that UK scientists have access to the data being generated internationally and that some of the essential core skills relating to the growth and basic biology of rice are available in the UK to those who require them.
- 3.14 The hexaploid nature of bread wheat makes genetic and genomic work difficult but understanding the genome and biochemical interactions in polyploid species is of fundamental scientific interest as well as being strategically relevant. Although *Brachypodium* is a useful "intermediate" species for some studies to augment the rice genome sequence, we conclude that a major investment in developing this as a diploid model for wheat is not justified. In addition, work on diploid barley will often provide a useful bridge to wheat. Nevertheless, we advocate attention on hexaploid wheat.
- 3.15 **Brassicas** We support continued work on Arabidopsis that provides insights into basic plant processes. Although some of the knowledge gained will find application in the improvement of *Brassica* crops, there is both more scope and a clear need for *Brassica* crops to set the agenda for research in Arabidopsis. Moreover, work directly on crop species is required in order to understand crop-specific traits. There is still a paucity of examples where Arabidopsis genomic information has been used to improve *Brassica* crops. Arabidopsis therefore still needs to prove its true worth in this respect.
- 3.16 *Legumes* Internationally funded work is under way on *Medicago truncatula* and should be continued, with due emphasis on economically and environmentally important crop traits.
- 3.17 *Solanaceae* Tomato remains the most intensively researched *Solanaceae* genome, exploiting its relatively simple diploid genetics and applicability for potato, pepper and aubergine. We support a contribution to the international effort to sequence the tomato genome.
- 3.18 *Non-food crops* It is not yet possible to define a core set of non-food crops as the choice is very much product dependent and should not be limited to the existing crops. Many

different plants are currently being evaluated for biopharmaceutical production, others for the production of materials such as fibre and oils. Work on biomass willows will benefit from the completion of the genome sequence of poplar, a related species.

3.19 For all sequencing work close integration with the principal sequencing centres worldwide should continue and public access to data from such centres is essential. In paragraph 4.38 we propose a mechanism to ensure that this occurs. Future access to the principal UK centre, the Sanger Institute's Sequencing Unit, will depend upon high-level agreement with the Wellcome Trust over availability, costs and mission for the Sanger Institute. Here we urge distinction between science-driven analyses, particularly of microbial genomes but also pest and crop genomes, and routine service analyses. In the event that the Sanger facilities are unavailable we consider that the relevant BBSRC committees should not be inhibited from funding high priority work outside the UK.

Recommendation 5: BBSRC should focus future investment in functional genomics in the context of identifying important crop traits in wheat, brassica, legumes, forage *Gramineae*, and *Solanaceae*. Largescale genome sequencing should only be undertaken through partnership with national and international collaborators and ensuring that sequence data are publicly available.

Non-food crops

Current work on non-food uses of crops is fragmented. Two government initiatives have 3.20 made a start to address the problem. First is the establishment of the Government Industry Forum on Non-Food Uses of Crops to provide strategic advice to government and industry on how to promote the development of non-food crops in the UK. Second is the recent launch of the National Non-Food Crop Centre to bring together scientists, producers and industrial users to develop specific projects, strategies and networks supporting the non-food uses of crops. Defra is also leading the development of a government-wide Non-Food Crops Strategy¹³. It is therefore timely to establish a coherent approach across BBSRC and Defrafunded research for the non-food uses of crops that takes account of and influences future markets and draws on the scientific and user expertise available through the National Non-Food Crop Centre. While investment has been significantly greater elsewhere (for example in the USA), economic and environmental constraints differ and it will be necessary to develop crops and products suited to northern Europe and the UK economy and agriculture. This will require significant investment that must capitalise on international collaboration, while allowing flexibility to develop non-food varieties of crops suitable for local needs and markets.

> Recommendation 6: Taking the government-wide Non-Food Crops Strategy into account, BBSRC should develop a strategy for research on non-food uses of crops that fosters an appropriate science base to serve current and future producer and end-user requirements.

Pests, pathogens and weeds

3.21 One of the principal challenges for crop science is to develop methods for durable pest and disease resistance. This requires complementary progress in genomic analysis of host and pathogen, together with an understanding of population genetics and epidemiology, to ensure efficient deployment of genetic control that minimises the risk of resistance

¹³ Non-Food Crops Strategy: Defra draft consultation document (March 2004)

breakdown. Corresponding attention needs to be given to balancing modern genomic analysis for pest and weed control with population ecology to minimise the risk of novel methods reducing biodiversity.

- 3.22 The choice of fungal and oomycete pathogens for genome analysis and functional genomic characterisation should be based upon:
 - the occurrence and economic impact of the pest or pathogen;
 - the genetic tractability of the organism and its host, in particular:
 - the advantages to be accrued from comparative genomics, whereby the whole is greater than the sum of the parts;
 - concomitant availability of the host genome sequence.
- 3.23 Of the potential pathogen candidates for study as model organisms, *Magnaporthe grisea* (the rice blast fungus), *Fusarium graminearum* (the wheat head scab fungus) and *Ustilago maydis* (the corn smut fungus) are already in draft sequence¹⁴. *Magnaporthe grisea* has the potential to provide a model system with good genomic resources and experimental tractability to underpin cereal pathogen work, particularly when used in comparative studies with less genetically amenable species. There should be an ongoing programme of genome characterisation and gene functional analysis in important pathogen species, accompanied by development of bioinformatic resources and expertise. Potential target species for genome sequencing at an early stage include:
 - *Mycosphaerella graminicola*: the causal agent of wheat blotch, the most severe fungal disease affecting wheat in the UK, and the agent responsible for most fungicide applications within Europe;
 - Peronospora parasitica: an obligately pathogenic oomycete which causes downy mildew and offers tremendous potential as a reservoir for identification of avirulence gene products that can be utilised for the study of plant resistance responses, and for comparative analysis with *Phytophthora infestans*;
 - *Blumeria graminis*: the causal agent of powdery mildew of wheat and barley, an obligate pathogen of economic importance; comparative genomic analysis offers great potential because of its experimental intractability.
- 3.24 In the longer term there should be an emphasis on development of high throughput technologies for gene functional analysis in microbial pathogens to provide more systematic analysis of infection processes and the development of disease.
- 3.25 Viral genomes are small compared with oomycetes and fungi and it is probable that sequencing plant viral genomes will become routine.
- 3.26 Currently the status and future directions of pest sequencing remain unclear. One strong candidate for UK crop science is the pea aphid, *Aphis pisi*. There is currently no sequence available for a plant pathogenic nematode sequence despite their economic importance but we expect this to change during the next ten years and a prime candidate for UK agriculture is the potato cyst nematode.
- 3.27 Emphasis should be placed on the population structure of pests and pathogens in the field in order to advance genomic-based research to practical economically sustainable agriculture.

¹⁴American Phytopathological Society (2003) Microbial genomic sequencing: perspectives of the American Phytopathological Society. http://www.apsnet.org/media/ps/MicrobialGenomicsSeqFinal03.pdf accessed 06/02/04

Recommendation 7: BBSRC should support genome sequencing and gene functional analysis of pests and pathogens and ensure that this is developed within a population genetic and epidemiological framework to promote durable pest and disease control. Initial organisms for sequencing and functional genomics should be selected from the following candidate organisms: *Mycosphaerella graminicola, Peronospora parasitica, Blumeria graminis* and *Aphis pisi.*

Capitalising on fundamental research in plant science

- 3.28 Many projects classified under plant science, as well as many of those under crop science, are motivated in part because of their long-term relevance to improving crop production. Regrettably, there is little or no evidence to date that the high level of investment in plant science is having a significant impact on strategic and applied research in crop science. Indeed there was considerable scepticism amongst respondents to the questionnaire about the effectiveness of knowledge transfer from models to crop production and a view that the gap between plant and crop science is widening. The problem may be two-fold.
- 3.29 First, the knowledge from plant science is relevant but is not being promoted. This reflects problems in communication between plant and crop scientists. It may also reflect a time delay: it is apparent that the time required to extract information on gene function from the *Arabidopsis* genome has been underestimated. The application of such information to crop improvement can be a major task.
- 3.30 Second, much of the knowledge from plant science is not yet exploitable for the development of novel crop traits useful for plant breeders and commercial exploitation. This disparity arises from the gap between the reductionist, 'bottom-up' approach of plant science and the trait-driven, 'top-down' approach of crop science. Plant science has tended to focus on the study of single traits in isolation. More work is still needed on model plants but, because the level of organisation in crop systems is complex, greater integration of plant science within a crop science framework is required. Plant science is exploitable but exploitation needs to be specifically resourced.
- 3.31 Mathematical modelling has an important role to play in integrating work at the sub-cellular and cellular level with whole plant performance. In particular, modelling should be exploited to identify critical scales *in planta* for plant science to impact on breeding strategies and selection of important traits. This will require close integration of modelling with corresponding experimental programmes.
- 3.32 Our view is that much of plant science has been driven primarily by questions of basic biology that are intrinsically interesting but divorced from crop science research. This, in part, reflects the difficulty of working with crop species in terms of the development of genomic information but instead of the gap narrowing, it is widening. While retaining the best of the excellent basic work, we suggest that there is now more scope and indeed an urgent need for crop science to set the agenda within plant science, particularly in BBSRC institutes.
- 3.33 If the potential benefit of advances in basic research for crop improvement is to be realised, effective targeting of resources will be crucial. Financial incentives will be required in order to move the focus of research towards crop science. Whilst strongly supporting the need to foster a strong UK basic plant science capability we conclude that the current balance of BBSRC funding between basic plant science and crop science (see Tables 1, 2 and 3) is inappropriate. A package of measures to enhance BBSRC's support for crop science and to

assist the implementation of the other scientific priorities we have identified is set out in paragraphs 4.10 to 4.29 and recommendations 9 to 13.

Recommendation 8: BBSRC should seek to re-balance its plant science research portfolio to place greater emphasis on crop science and to promote the transfer of knowledge from plant science to crop science by implementing recommendations 9 to 13.

Chapter 4 Delivery mechanisms for crop science research

Achieving a co-ordinated, critical mass of crop science research

Fragmentation of UK funding

4.1 Many respondents attributed the lack of coherence in research strategy for crop science to fragmentation amongst funding agencies (see Annex 4 and paragraph 2.14). We recognise that the major funders, BBSRC, Defra and SEERAD, necessarily have distinct roles. The funders maintain close contact at various levels: for example, Defra and SEERAD are represented on Council and the relevant BBSRC research committees, and each is consulted in the development of the others' research strategy. Nevertheless it is clear that fragmentation and lack of coherence in funding has significantly limited the development of crop science in the UK.

Links with Defra and SEERAD

- 4.2 With current annual budgets for crop and plant science research of £64.8m, £26.4m and £15.5m, respectively, BBSRC, Defra and SEERAD account for 82% of total UK expenditure (Table 4). The need for co-ordination is compelling, especially in facilitating a coherent sequence from basic, through strategic to applied crop science within a sustainable agricultural framework. There are two serious problems in achieving co-ordination. These concern the scale at which planning and interaction occur amongst the funders.
- 4.3 While there is cross-funder input to strategic planning, the emphasis is on consultation and there has to date been no formal attempt to construct an overarching strategy for crop science research. We accept the need for funders to maintain responsibility for different missions but we suggest that more needs to be done to reduce the fragmentation of funding. Our proposal below for a steering group goes some way towards addressing this from the perspective of BBSRC.
- 4.4 The scale of interaction between the funders generally occurs at the level of individual scientists or group leaders. This is essential for scientific progress but it favours tactics at the expense of strategy. Fragmentation within funders, notably between CSG and research grants in BBSRC, and amongst policy divisions within Defra for arable crops and horticulture, exacerbates the problem.
- 4.5 We understand that Defra intends to use its research resources to support longer-term projects to complement relevant research of other funders, particularly BBSRC, in fundamental sciences by creating 'Crop Genetic Improvement Networks'¹⁵. These networks will bring together the relevant research and genetic resources through strategic partnerships between Defra, BBSRC, research organisations and breeders, and focus these resources on research supporting the genetic improvement of specific crops (wheat, oilseed rape, oats, pulse crops, short rotation coppice, and *Miscanthus*). In principle, Defra networks could be well placed to make effective use of the resources and data generated from BBSRC-funded research but successful transfer demands continued strategic co-ordination between BBSRC and Defra and more investment.
- 4.6 We recommend below mechanisms to co-ordinate funding within BBSRC (recommendations 9 to 11). Were there to be a corresponding co-ordination amongst policy divisions within Defra, the resulting interface between BBSRC and Defra would be supported by a co-ordinated funding of £64.8m and £26.4m rather than as a series of much

¹⁵ BBSRC Business, October 2003 page 10

smaller interactions: the whole would be greater than the sum of the parts. Co-ordination with SEERAD demands more co-ordinated planning and greater commitment of reciprocal funding for large-scale projects outlined in Chapter 3.

Challenges and solutions for BBSRC

- 4.7 The targets we have proposed for future crop science research are wide ranging. The challenge for BBSRC is how to pursue a coherent strategy for meeting these targets from two funding streams whose awarding mechanisms are based on different criteria. The CSG is used to support long-term core science in BBSRC institutes while the responsive mode is used for shorter-term, competitive bids, mainly from universities but since 2000 available to institutes up to a limit (Council sets an annual 'cap' on the total amount each institute may apply for). It is essential that these two modes are co-ordinated within the framework of the crop science strategy. Institutes have an important part to play but there is also a need for co-ordination within and between institutes as well as between institutes and universities.
- 4.8 Opening responsive mode funding to institutes has widened the gap between plant and crop science as institutes have been expected to seek external funding and consequently have become more like universities in pursuing shorter-term projects, often on model plants. Many of these have delivered high quality international science that BBSRC demands. However, BBSRC's institutes should also maintain a focus on long-term strategic research without which the rationale for their existence is diminished.
- 4.9 We consider that the solution requires:
 - co-ordination at the national level;
 - taking a longer-term view and encouraging longer-term and larger projects towards strategic goals in crop science research;
 - co-ordination of responsive mode and CSG funding within BBSRC, without stifling creative research.
- 4.10 We propose a high-level steering group, of limited life-span, to drive forward the crop science strategy. The group should be chaired by a Council member and include the relevant Institute Directors (JIC, RRes, IGER, SRI, IFR) and research committee chairs, representatives of Defra and SEERAD, and with the ability to co-opt members from industry and other appropriate bodies such as Warwick HRI.
- 4.11 The steering group should oversee the co-ordination of crop science research: (i) within BBSRC, to ensure that the different CSG programmes and the university grants portfolio develop in synergy, including the co-ordination issues raised in the *Review of Sustainable Agriculture* and (ii) between BBSRC and other national funders. It should maintain a strategic overview of the development of the crop science research and training portfolio. It should be answerable directly to Council and report to Council annually. Its advice should be central to both the Institute Assessment Exercise and the research committees' prioritisation exercises. It should develop and apply measures of research output to seek excellence within a framework appropriate to crop science. We consider that the steering group should have a limited life-span, sufficient to ensure that the mechanisms we have suggested, and co-ordination in particular, are functioning effectively.

Recommendation 9: Council should establish a high-level steering group, chaired by a member of Council, to maintain a strategic overview of the development of the BBSRC crop science research and training portfolio, including the implementation of recommendations 1 to 8. Council should also consider the need to establish co-ordinated programmes on specific crops or groups of crops. The steering group should ensure co-ordination within BBSRC so that the relevant institute programmes and the university grants portfolio develop in synergy with other national funders.

Role of institutes

- 4.12 Institute programmes supported by the CSG make a major contribution to Council's crop science portfolio (Chapter 2). At present effective co-ordination between the programmes within and between individual institutes, between BBSRC institutes and the relevant SEERAD institutes and between institutes and university projects is lacking. We consider that the current low level of research integration is an obstacle to progress.
- 4.13 We considered the redistribution of crop science research amongst institutes, for example, moving wheat research to a single site or going as far as developing some institutes as centres of excellence in plant science only. We concluded that the gains would not outweigh the losses and felt strongly that it was essential to underpin crop science with relevant plant science and that knowledge transfer would be increased if the goals of plant and crop science were better integrated.
- 4.14 We propose instead that three co-ordinators should be appointed with the initial aim of developing integrated programmes across the relevant BBSRC institutes, one for cereals and grasses, a second for non-food crops, and the third for brassicas, legumes and *Solanaceae*. The co-ordinators should, from the outset, seek to co-ordinate research across the whole of the relevant science communities and develop close links with other funding agencies, especially Defra, SEERAD and DFID and leading EU collaborators. They should play a key role in ensuring efficient management of germplasm and data (see Recommendation 3, paragraphs 3.6–3.7). The longer-term goal should be to establish full integration with complementary research at BBSRC institutes, universities and SEERAD institutes. The co-ordinators should be working scientists based in the community. They should be members of the proposed high-level steering group and report to Council annually. The model we propose here is similar to that recently endorsed by Council for co-ordination of soil science across BBSRC institutes.
- 4.15 In order to ensure that fully integrated programmes in these three areas are successfully implemented, it is essential that the co-ordinators have budgetary control. Close liaison with Institute Directors is crucial. Co-ordinators' detailed proposals for the scope of future research and allocation of funding must be approved by Council.

Recommendation 10: BBSRC should appoint co-ordinators for three areas of crop science, one for monocots, a second for non-food uses of crops, and the third for brassicas, legumes and *Solanaceae*, in order to develop and co-ordinate cohesive programmes of work across BBSRC institutes with the longer-term aim of integrating the work at BBSRC institutes, SEERAD-sponsored bodies and universities.

Role of universities

- 4.16 University departments are centres of excellence for specific research areas within plant and microbial science along with additional basic work on pests, weeds, soil science and post harvest biology. They are also centres of expertise for certain genomic and visualisation techniques. Much of the national expertise in population genetics and in mathematical modelling is also located within universities. There is currently a ratio of 2:1 in funding for plant to crop science research (as defined in Table 1).
- 4.17 Universities should be encouraged to undertake more work on crop plants and, in particular, to apply for grants that seek to exploit genomic information from model plants. Financial incentives to collaborate with BBSRC and other institutes and awards longer than the typical 3-year grant will be needed to achieve tractable programmes and to stimulate interest in working on complex crop traits.
- 4.18 Expansion of crop science research in university departments together with enhanced links with BBSRC institutes is important in fostering the role of universities in training future plant and crop scientists and in introducing mathematical modellers and population geneticists to work in crop science.

Responsive mode

- 4.19 At present responsive mode grants amount to an annual commitment of some £14m, which accounts for around 40% of BBSRC's research grant expenditure in crop science (Table 1). However, the current structure and priorities of the research committees militate against the development of a well co-ordinated strategy for crop science. In common with other important elements of BBSRC's overall portfolio (e.g. sustainability, microbiology and animal science) crop science applications are considered across four of the current seven committees¹⁶ with consequent low representation of crop scientists on any one committee. Each committee sets its priorities independently and no single committee has an overall responsibility to promote and focus work in crop science in responsive mode.
- 4.20 Council's Sustainable Agriculture Review¹⁷ suggested a revision of the committee structure leading to the formation of a dedicated sustainable agriculture committee. We consider that a related model for crop science would foster a consistent approach to prioritisation and peer review and facilitate better co-ordination. We propose that a single committee should be responsible for assessing crop research grant applications. The committee should have representation from Defra and SEERAD and would be responsible for developing a strategy for crop science in responsive mode. Importantly this should include policies to favour larger and longer research programmes including collaborative projects between institutes and universities. It should report annually to the Council high-level steering group.
- 4.21 We recognise that a dedicated committee could separate crop research from plant science. Therefore the committee should either have overlapping membership with the current Plant and Microbial Sciences Committee or (preferably) plant sciences should be moved so that it comes under the new committee. Since the new committee would have a number of common interests with sustainable agriculture, a combined sustainable agriculture and crop science committee should be considered.

¹⁶ Agri-Food, Plant and Microbial Sciences, Genes and Developmental Biology, Biochemistry and Cell Biology

¹⁷ Review of BBSRC-Funded Research Relevant to Sustainable Agriculture (2002)

4.22 We also consider that it is vital to continue fostering excellent basic plant science. Therefore, plant science research should remain within the remits of other relevant BBSRC committees (currently BCB and GDB) where it addresses fundamental biological concepts.

Recommendation 11: Council should revise the current committee structure with the aim of forming a single committee with responsibility for promoting and focusing responsive mode funding for crop science, plant science and sustainable agriculture.

CSG funding

- 4.23 We have noted earlier the major contribution to Council's crop science portfolio made by the institute programmes supported by the CSG. Although these programmes take account of BBSRC's high-level strategic objectives there is a significant amount of freedom over how the CSG is used. Whilst it is important that Institute Directors maintain flexibility in the way CSG is allocated, greater accountability is needed with respect to the way in which individual projects relate to Council's crop science strategy. At present crop science programmes/projects supported by the CSG lack sufficient transparency to enable a clear overall picture of activity to be obtained. It is essential that reporting of CSG allocations should specifically identify the crop science programme objectives of the institutes, distinct from other aspects of plant science, and indicate the associated resources together with intended timescales. Such information would greatly assist the proposed high-level steering group and new research committee in fulfilling their roles and facilitate greater cohesion of crop science research.
- 4.24 In keeping with the recommendation from the Sustainable Agriculture Review, we propose that institutes should report annually to the proposed high-level steering group:
 - accounting for the proportion of the CSG dedicated to crop science;
 - indicating the anticipated relationship of the current institute crop science programme and proposed future work with that of other institutes, universities and other public sector laboratories where appropriate.

Recommendation 12: Institute reporting procedures should clearly identify dedicated crop science projects that are distinct from other aspects of plant science and indicate the strategic importance of the project, the total funding of the project and the contribution made from CSG.

Funding BBSRC crop science research

- 4.25 Maintaining vibrant, world class UK research in plant science is an essential component of the future strategy for crop science. BBSRC should therefore continue to support basic plant science research at the current level of ~10% of its current annual expenditure¹⁸. However, we consider that a higher proportion of this basic work should be targeted at applying the knowledge and skills in the basic plant science community through to practical application in plant breeding and sustainable diversified agriculture.
- 4.26 To achieve this will require a cultural shift towards greater recognition of the strategic importance of crop science. This will require refocusing of institute CSG funds as well as

¹⁸ Currently basic plant science research accounts for £28.6m of BBSRC's gross expenditure of £275.8m.

the responsive mode. It will also require incentives to encourage basic plant scientists to meet the challenge of applying their expertise to complex crop plants.

- 4.27 Firstly, Council should make the transfer of knowledge from basic plant science to crop research a high priority. Coupled with this we suggest that Council should set a notional target of around 15% of its support for basic plant science (equivalent to ~£4.3m from the current expenditure of £28.6m) to be spent towards achieving this priority.
- 4.28 Secondly, in order to catalyse an immediate shift in emphasis, we propose that additional funding of £12m (equivalent to an increase in 20% of the total current spend of ~£65m on plant and crop science research) is provided for work on high priority crop science objectives listed in paragraphs 3.3 to 3.4. Proposals should then be invited against specific crop science objectives.
- 4.29 We also propose the following top slicing of the combined plant and crop science budget:
 - up to £3m p.a. to fund training and career development, crop co-ordinators and technical expertise for maintenance and curation of genomic information;
 - up to two tranches, each of up to £4m p.a., for competitively funded work in crop genomics and crop science objectives where there is matching funding from other national or international funders.
- 4.30 It is essential that all bids for additional funding, including those for matched funding, should be peer reviewed and competitive with other calls upon BBSRC funding.

Recommendation 13: Council should:

- seek to increase the proportion of the basic plant science budget that addresses the priority of knowledge transfer from plant to crop science whilst maintaining the current level of support for basic plant science;
- provide additional funding of £12m for new research aimed at the specific crop science objectives set out in paragraphs 3.3 to 3.4;
- ensure that there is flexibility in funding to support large-scale, collaborative projects with external matching funding up to £4m as well as recurrent funding for co-ordination, training and data management.

Enabling public-good plant breeding

- 4.31 The responses to our consultation exercise identified a widely perceived need for publicgood plant breeding in order to address crops and traits not emphasised by multinational commercial interests and to restore public confidence in plant breeding. The agglomeration of multinational agribusinesses and withdrawal from the UK has exacerbated the problem, with increasing focus on fewer crops and little commercial incentive to address targets linked to sustainability.
- 4.32 We propose that a national plant breeding initiative should be established to develop germplasm for crops and traits ignored by multinational commercial interests. In this respect even wheat is becoming an "orphan crop" as greater commercial returns accrue from crops such as maize. This initiative should seek to promote and match crop science research with routes for commercial development of germplasm for a range of crops suited to changing agricultural, commercial and environmental demands, principally in the UK and Western Europe. There is a clear opportunity for BBSRC to bridge this gap by working closely with Defra, building on existing partnerships such as the Defra Crop Genetic Improvement

Networks (see paragraph 4.5). The methodology and outputs should be publicly available. The initiative should not be restricted to mandate crops but maintain flexibility to allow the breeding of minority crops, especially non-food crops.

- 4.33 The overall aims of the initiative would cover a spectrum of activities as follows:
 - advancing germplasm to pre-commercial release for subsequent release to the public domain or to be retained by public sector research establishments;
 - advancing germplasm to commercial release through affiliated companies;
 - delivering pre-breeding sources of useful genes in appropriate germplasm and markers and other tools to facilitate their exploitation to companies capable of developing products from them.

The appropriateness of one or the other is likely to be crop specific and we advocate all three routes.

- 4.34 The commercial focus of the initiative should be successively to:
 - promote and diversify plant breeding to ensure that crops are suited for UK conditions;
 - promote the development of crops suited to UK/European needs;
 - develop a market for UK technology e.g. in relation to crops for less developed countries as well as the UK.
- 4.35 We do not consider that the initiative should be based at a single site. Currently no UK establishment has the expertise relevant to all major crop groups. We therefore envisage a virtual initiative with genetics and breeding focused at the three principal BBSRC institutes, JIC, RRes and IGER and with additional activity at SCRI and Warwick HRI. There are a number of possible locations for field trials including *inter alia* BBSRC institutes and NIAB.
- 4.36 The form of the national plant breeding initiative will require further discussion. It is intended to support rather than compete with commercial plant breeders. It will require national co-ordination in order to ensure efficiency and economy of scale in the underpinning genomics. It will also require substantial co-ordination of effort amongst the principal funders. We consider that BBSRC should drive the setting up of this initiative, because of the need for scientific leadership, but that it is probably not the organisation to run it in the long term.

Recommendation 14: BBSRC should take the lead to establish a national plant breeding initiative, in partnership with other funders drawn from government, charities and the private sector that would promote public-good plant breeding by establishing crop genetic improvement programmes with the aim of providing improved germplasm and technology for the development of new varieties.

International co-ordination and co-operation

4.37 With few exceptions (e.g. *Medicago* sequencing) there has been neither an obvious UK strategy nor a cohesive approach for international collaboration on crop science. We consider that BBSRC should take a more pro-active stance towards international collaboration and we propose a number of ways this could be achieved, after discussions with an extensive list of international experts (Annex 3).

- 4.38 The BBSRC's relationship with European partners, notably INRA, Wageningen UR and the Max Planck Institutes should be developed more fully, in recognition of the opportunities and overlap of objectives that already exist, and the advantages of a strong partnership within the wider European context. Following exploratory discussions we identify two starting points.
 - The potential should be explored for establishing medium-term joint funding with INRA, over a 5-year trial period, for joint work on the collation and exploitation of genomic information for crop species and for joint research facilities.
 - Similarly the advantages of joint funding with DFID for work on underpinning and strategic crop science, which would be of benefit to the UK and to developing countries, should be pursued.

Further possibilities exist and ought to be pursued for collaborative exchanges with the International Challenge Programmes of the CGIAR institutes in tackling major problems for drought tolerance, salinity and water use and deployment of durable resistance to pests and pathogens¹⁹.

- 4.39 International networks of researchers on major crop species and pathogens should be established to enable the identification of research priorities, the sharing of resources and ideas and to provide a point of interaction with similar communities in other countries. Networks should have funds to establish collaborative discussions with overseas partners. Within the short term (of the order of five years) the BBSRC and its stakeholders will need to develop a clear idea, shared with other international partners, of which areas of the science are going to be more effectively delivered at the international level, and to find a means to transfer the funding of such science onto an international footing.
- 4.40 A source of rapidly accessible funds for international partnership proposals needs to be developed on a scale suitable to contribute to significant proposals for sequencing and development of major resources. This will require both short- and longer-term funding, which should be competitive with other areas.

Recommendation 15: BBSRC should seek to lead rather than respond in the development of international research programmes in crop science by strengthening relationships with INRA and DFID, among others, encouraging international networking and providing funds to facilitate international partnerships.

Training and career development

4.41 The problems of a shortage of suitably trained personnel and limited career development apply to a number of areas of BBSRC science. It is especially serious in the case of crop researchers (Table 6). It is clear to us and to many of the respondents and consultants that training in plant science *per se* will not produce scientists capable of undertaking crop research. Moreover, failure to tackle these problems could seriously undermine the ability of the UK to provide scientific solutions to changing national demands in agriculture over the next 20 years. It would also inhibit the shift towards crop science that we advocate in BBSRC's research portfolio.

¹⁹ Unlocking Genetic Diversity in Crops for the Resource-Poor: A proposal for a CGIAR Challenge Programme (2003)

- 4.42 Since these problems are not unique to crop science most of the solutions we list below are generic to other areas of BBSRC science where there are shortages of skilled researchers. We identify the following solutions:
 - **Postdoctoral Fellowships** A targeted, high-profile, well-resourced, postdoctoral fellowship scheme, analogous to the NSF scheme that attracted highly talented individuals into plant science, could be used to recruit scientists into an under-subscribed area such as crop science. The fellowships should be for four years and allow periods of placement in overseas laboratories so that they learn the most up-to-date technologies and scientific developments in order to bring new skills to UK crop science.
 - *Ph.D. training* We need to produce a new breed of crop scientists, who are well trained in molecular plant biology as well as genetics and plant breeding so that they can bridge the gap between plant and crop science. Four-year Ph.D. programmes with some laboratory rotation are therefore recommended. One possibility is to introduce 2+2-year university-institute programmes to promote broader training.
 - *M.Sc. training* Future crop scientists will require adequate training in biometrics, genetics and plant breeding. BBSRC should support at least 10 M.Sc. studentships p.a. specifically in applied plant science and plant breeding as well as continuing to fund places in more general related topics such as biomathematics, genetics and bioinformatics. We specifically encourage support for courses run jointly between suitable university departments and appropriate research institutes.
 - *Targeted recruitment and start-up packages in institutes* Postdoctoral fellowships and postgraduate studentships alone will not solve the problem without the opportunities for planned recruitment into institutes. Council should ensure that BBSRC-sponsored institutes have sufficient incentives for career development and technological resources to encourage talented and well-trained young scientists to pursue long-term, strategically important projects.
 - University-Institute Fellowships It is important to maintain connections between universities and institutes. One way to foster this is by introducing part-time fellowships to allow reciprocal exchange of senior scientists between universities and institutes.

Recommendation 16: BBSRC should review its training programmes and career development for crop scientists by considering the introduction of targeted schemes for training and recruitment at senior, postdoctoral and postgraduate levels including international secondments.

Public perceptions

- 4.43 As in other areas of science, the identification and pursuit of research priorities, and development of research strategies for crop science should take into account attitudes, concerns and aspirations of society as a whole, as well as those of specialist stakeholders such as industrial end-users. The problems of public perceptions of plant and crop science are widely acknowledged. Although BBSRC has already done much to improve communication and to assist public understanding of science there remains confusion in the minds of many of the public and indeed many scientists that genomically informed research necessarily involves the transfer of genes between different species.
- 4.44 In crop science, it is likely that public concern will continue to focus on the contribution of GM, both as a research tool and as a technology in crop development, the application of

plant science to crops in less developed countries, and long-term sustainability and safety of the food chain. It is also important to emphasise that transgenic technology can be used to help understand gene function and that this understanding can be used to look for useful non-GM variants.

4.45 Given the breadth and potential importance of crop science, BBSRC should draw up a communication strategy for publicising this review and its findings not only to those with a professional interest but also to the wider public by attending relevant exhibitions and other events. The aim should be to demonstrate how priorities for crop science research link to the aspirations of society as a whole.

Recommendation 17: BBSRC should seek to increase publicity for public-good plant breeding and to emphasise the role of genomically-informed but non-transgenic approaches to crop science research.

Annex 1: Terms of reference and membership of the review group

Terms of Reference

- 1. To review the BBSRC's current research through CSG, responsive mode and other funding relevant to crop science, analysing its strengths and weaknesses in the context of a medium to long term (i.e. 10 20 year) strategy for UK crop science.
- 2. To consider how BBSRC's research priorities in this area relate to those of Government Departments, and in particular to DEFRA and SEERAD, and those of industry, in the light of recently published aims and objectives, and other relevant reviews.
- 3. To advise how BBSRC's priorities for future research in crop science (to include food, feed and non-food uses such as bioproducts, biofuels and biomass production) should be established and developed, in particular to recommend a strategy:
 - that optimises the transfer of outputs from basic plant science (including model systems) into crop science within a sustainable agricultural framework;
 - that incorporates the most appropriate funding arrangements to support crop science research in institutes and universities to ensure they retain the capability to deliver the research in the medium- to long-term, and take account of the various stakeholders' needs;
 - that promotes synergistic structures and partnerships:
 - within and between BBSRC institutes
 - between BBSRC institutes and the universities
 - between BBSRC and other funders nationally and internationally.
- 4. To report to Council early in 2004.

Membership of the Crop Science Review Panel

Professor Chris Gilligan (Chairman) Department of Plant Sciences, University of Cambridge

Dr Ian Bancroft Department of Crop Genetics, John Innes Centre

Dr Tina Barsby Biogemma UK Ltd, Cambridge

Professor Jim Dunwell School of Plant Sciences, University of Reading

Professor Ian Graham Department of Biology, University of York

Dr Donal Murphy-Bokern Sustainable Farming Food and Fisheries Science Division, Defra

Professor Francesco Salamini Max Planck Institute for Plant Breeding Research, Köln, Germany

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Professor Nicholas Talbot School of Biological and Chemical Sciences, University of Exeter

Dr Rosi Waterhouse Scottish Executive Environment and Rural Affairs Department, Edinburgh

Professor David White Director, Science and Technology Group, BBSRC

Observer

Dr Sue Armfield DTI Bioscience Unit

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Dr Malcolm Anderson Consultant

Dr Alf Game Head of Plants, Microbes and Genetics Branch, BBSRC

Dr Huw Tyson Senior Programme Manager, Agri-Food Branch, BBSRC

Annex 2: Consultation document and questionnaire

FUTURE DIRECTIONS IN CROP SCIENCE RESEARCH

A consultation by the Biotechnology and Biological Sciences Research Council (BBSRC*)

You are invited to submit your views, or those of your organisation, on the priorities for crop science research over the next 10-20 years and on the facilities and support for such research in the UK.

This consultation forms part of a review being undertaken by the Biotechnology and Biological Sciences Research Council (BBSRC), which will help in defining future research priorities. The BBSRC is the UK's principal funder of basic plant science research. In 2002-03, from an overall research spend of £215M, BBSRC invested approximately £34M on research in crop science and a further £26M on plant science research that underpins crop science. The review will help to ensure that BBSRC-funded research remains relevant to the needs of UK agriculture as it faces a period of significant change.

Definition and process

For the purposes of this review, 'Crop Science' is defined as 'science that provides knowledge and technology serving the exploitation of cultivated plants'. The review encompasses research on crop plants grown in the UK and elsewhere; it includes crops grown for food, feed and non-food uses; also horticulture, relevant plant pathology, and both biotechnological and traditional approaches to crop improvement.

All relevant views are welcome, but responses to the six questions below are particularly invited. Please submit responses by email to crops.review@bbsrc.ac.uk by 30 September 2003. Please indicate whether you are responding on behalf of your organisation or in a personal capacity. **BBSRC** is consulting widely: please see the list the web site on at http://www.bbsrc.ac.uk/society/consult/crop, where this document is also available. Please indicate the names of other individuals and/or organisations that you consider should be included in this consultation.

Outcomes

Submitted views will be considered by the panel that is reviewing BBSRC's portfolio of crop science research. The panel's terms of reference are attached at the end of this document. The panel will report to the BBSRC Council early in 2004. A report on this consultation and the views submitted will be published on the BBSRC web site together with the final report of the review panel.

* The Biotechnology and Biological Sciences Research Council (BBSRC) is one of seven Research Councils sponsored through the Government's Office of Science and Technology. The Council's mission is to fund internationally competitive research, to provide training in the biosciences, to encourage opportunities for knowledge transfer and innovation and to engage the public and other stakeholders in dialogue on issues of scientific interest. Details of BBSRC and the research that it supports can be found on the web site at http://www.bbsrc.ac.uk/science/Welcome.html

FUTURE PRIORITIES

1. In your view, what are the most important **challenges** for crop science over the next 10-20 years:

(a) in the UK?

(b) internationally?

Please indicate order of importance, with reasons.

- 2. What are the **priorities** for UK research in crop science necessary to address the above challenges? Please indicate order of importance, with reasons.
- 3. In your view, what are the key **barriers** (within both publicly and privately funded research) to addressing the above challenges?

FACILITIES

4. (a) How *important* are the following **facilities** to UK crop and related plant science research and training in addressing the challenges in Q1 above (critical, very, fairly, low or none)?

(b) If you are a researcher, how highly do you rate the *access* currently provided in the UK to such facilities (excellent, good, satisfactory, poor or very poor)?

- genomic resources (e.g., arrays, BAC and other libraries, tagged populations)
- genomics facilities (e.g., transcriptome analysis, TILLING, RNAi, etc)
- large-scale facilities for proteomics
- large-scale facilities for metabolomics
- germplasm collections (egg, seed and mutant stocks)
- field experiments
- climate change research facilities
- data and materials: facilities for capture, storage, curation and distribution.

MECHANISMS

- 5. Please comment on whether, in your view, the following provisions are appropriate to deliver future research needs, and if not, how they should be modified:
- (a) the **current structure** of the UK crop science research community (for example, the balance of research in universities *versus* research institutes and applied research organisations)
- (b) the **mechanisms** for the support of UK crop science research (for example, Research Council responsive mode funding, Research Council coordinated initiatives, Research Council core-funded programmes at research institutes, Government Departments' research programmes, industrial support through Levy Bodies, Government grant-aided support for industrial research through LINK, regular workshops, central facilities)
- (c) the mechanisms for the support of **international research** in crop science
- (d) the mechanisms for the support of post-graduate, post-doctoral and other research **training** for UK crop science research.

6. BBSRC supports research and training in a broad range of the biosciences. Do you consider that the **current level of BBSRC funding** for research in crop science and related plant science is: too low/about right/too high?

Please give reasons.

OTHER COMMENTS

7. Please provide any further comments on any issues that are relevant to the review.

Annex 3: Respondents to the consultation exercise

INTERNATIONAL EXPERTS

The following were interviewed by panel members and/or submitted responses to the questionnaire.

Dr Ian Baldwin Professor Dianna Bowles Professor Michel Caboche Dr Bernard Convent Professor Mike Emes Professor Rick Dixon Professor Richard Flavell Professor Richard Flavell Professor Peter Langridge Dr Guy Riba Professor Chris Somerville Professor Lothar Willmitzer Dr John Witcombe

RESPONSES RECEIVED

Universities

Official responses Professor Nick Battey Professor David Baulcombe Professor Keith Edwards Professor Robert Freedman Professor Phil Gilmartin Professor Dike Holdsworth Professor John Mansfield Professor David Richardson Renee Taylor Dr Kerr Walker Professor Colin Webb *et al*

Personal responses

Professor Peter Belton Dr Gerard Bishop Professor Nigel Brown Professor Ken Buck Professor Andrew Cobb Professor Keith Edwards Professor Richard Ellis *et al* Dr Angharad Gatehouse *et al* Professor Mike Jarvis Professor Jonathan Jones Professor Mike Kearsey Dr Peter Kettlewell Max Planck Institute, Jena, Germany University of York INRA, France Bayer Crop Science, Germany University of Guelph, Canada Samuel Roberts Noble Foundation, USA Ceres Inc, USA ex-JIC University of Adelaide, Australia INRA, France Stanford University, USA Max Planck Institute, Golm, Germany University of Wales, Bangor (and Manager, DFID Plant Sciences Research Programme)

Plant Sciences, University of Reading Sainsbury Laboratory, University of East Anglia Biological Sciences, University of Bristol Biological Sciences, University of Warwick Biological Sciences, University of Leeds University of Nottingham Imperial College at Wye Biological Sciences, University of East Anglia University of Wales, Bangor Scottish Agricultural College Satake Centre, UMIST

University of East Anglia University of Wales, Aberystwyth University of Birmingham Imperial College, London Harper Adams University College University of Bristol University of Reading University of Reading University of Newcastle upon Tyne University of Glasgow Sainsbury Laboratory, University of East Anglia University of Birmingham Harper Adams University College

Professor Ottoline Leyser	University of York
Professor Steven Neill	University of the West of England
Professor Toni Slabas	University of Durham
Dr Nicholas Smirnoff	University of Exeter
Dr Pietro Spanu	Imperial College, London
Dr Mark Sterling	University of Birmingham
Dr Simon Turner	University of Manchester
Professor Colin Webb et al	UMIST
Dr Paul Wood & Dr Derek Holloman	University of Bristol

Institutes (BBSRC and other)

Official responses

Professor Ian Crute	Rothamsted Research
Professor Bill Day	SRI
Professor John Hillman	SCRI
Professor Chris Pollock	IGER
Dr James Reeves	NIAB
Professor Chris Lamb	JIC
Professor John Snape	JIC
Dr Mike Solomon	HRI (East Malling)
Dr Nick Walton	IFR
Professor Michael Wilson	HRI

Personal responses

JIC
JIC
SCRI
JIC
HRI
IGER
JIC
JIC
JIC
Rothamsted Research
JIC
SCRI
SCRI

Industry

Dr Pete Berry	ADAS Boxworth
Dr Simon Bright	Syngenta
Dr Gareth Davies	Henry Doubleday Research Association
Henry Fell	Commercial Farmers Group
Dr John Fisher	British Crop Protection Council
Christopher Green	Semundo Ltd
Dr Graham Jellis	Applied Research Forum for Farming and Food

Anthony Keeling Angela Lea Hugh Oliver-Bellasis Scott Phillips Dr Pat Ryan Martin Sage Dr Roger Turner Dr Peter Werner Dr Geraldine Schofield

Government

Dr Steven HillDefra (GM Science and Regulation)Dr Donal Murphy-BokernDefra (Arable Crop Sciences & Pesticide Safety)Dr Rosi WaterhouseSEERAD

Farmer

Pitts Farm

Unilever

Elsoms Seeds Ltd

CPB Twyford Ltd

Elm Farm Research Centre

British Society of Plant Breeders

Syngenta Crop Protection

Royal Agricultural Society of England

Non-Governmental Organisations

Dr Donald Bruce Rupert Howes Dr Brian Johnson Dr Tom MacMillan Dr Sandy Thomas Church of Scotland Forum for the Future English Nature Food Ethics Council Nuffield Council on Bioethics

Annex 4: Summary of principal messages from consultation exercise

What follows is a digest of the principal messages that emerged from the responses to the Panel's consultation exercise. All responses were made available for the panel to consult. Each response was summarised with respect to its principal messages, including perceptions of the major UK challenges, international challenges, research priorities and barriers to progress, as well as comments on facilities and funding mechanisms. The summaries were produced by two panel members, one from academia, the other from industry. Separate summaries were also produced from the responses on facilities and mechanisms.

General messages

Fragmentation of funding

• Fragmentation amongst funding agencies with consequent lack of coherence in research strategy for crop science

Need for an integrated approach across different disciplines and funding agencies

• Greater strategic co-ordination and collaboration between institutes and universities needed

Public good plant breeding

- Widely-perceived need for public-good plant breeding:
 - to address crops and traits ignored by multinational commercial interests
 - to restore public confidence

Capitalising on fundamental research in plant science and balance of plant and crop science

- Investment in plant science is not having significant impact on strategic and applied research in crop science
 - There was considerable scepticism from some submissions about transfer of knowledge from model to crop production
 - Gap between plant and crop science perceived by many to be widening
 - Need to extend and exploit biotechnology already created in models into crops
 - Three-year timeframe too short to deliver crop science; emphasis of responsive mode on 'excellence of science' not conducive to funding of translation of model results to crops

International co-ordination and collaboration

• Call to maintain genomics research but need for co-ordination with international genomics programmes

Training and career development

• Problem of shortage of suitably trained personnel and career development for crop researchers

Public perceptions

• Problem of public perceptions of plant and crop science widely acknowledged

Miscellaneous

- Need for improvements in data curation for bioinformatics data and germplasm collection
- Calls for more work on crop genetics and conventional plant breeding
- Maintain internationally competitive fundamental plant science
- Role of predictive and integrative modelling is currently underestimated

- Institutes are becoming more like universities with switch in balance from strategic and applied towards basic science
- Need higher end-user relevance and to work more closely with stakeholders and industry

Challenges and Priorities

Require solutions to the following sets of problems:

- Climate change (including yield stability under extreme conditions)
- Lower inputs (driven by changes in CAP subsidies and environmental pressures)
- Durable pest and disease resistance
- Drought tolerance, salinity and water-use efficiency
- Linking food, diet and health

Selection of crop portfolio

Model crops

- Current models
 - Rationale of capitalising on Arabidopsis for fundamental study of plants accepted
 - Support for continued international effort on *Medicago* and possibly *Lotus*
- New targets
 - Some support for rice as model for monocots including cereals and grasses
 - Tomato (with advantages for potato, pepper and aubergine)

Impact of model species on crop production

- Considerable scepticism on successful transfer of plant science derived from model to crop science
- Concern that emphasis on model species may be <u>inhibiting</u> crop science; insufficient emphasis on crops vs. models
- Research should be crop-specific in certain areas such as pests and diseases

Non-food crops

- Current work in UK is piecemeal, lacking in economic and scientific strategy
- Important role for non-food crops, especially as replacement for fossil fuels
- Some considered UK was lagging behind Germany and U.S.

Non-temperate crops

• Some explicit support for work on traits for non-temperate crops where there are common goals such as drought, salinity or efficiency of water usage.

Sequencing pests and pathogens

- Possibility raised of integration with Sanger Institute
- Surprisingly no clear consensus and little discussion of which species to sequence: case made for *Peronospora parasitica*

Technical challenges

- Develop new breeding strategies informed by genomic information link breeding and research
- Apomixis, heterosis, perenniality, meiotic recombination, ploidy control, extension of growing season
- Predictive modelling:
 - for integrative biology of (individual) plants
 - to predict crop (i.e. population) performance
 - to assess impacts of change

Training

- Postdoctoral Fellowships: recommendation for targeted, high-profile, postdoctoral fellowship scheme analogous to the NSF scheme that attracted highly talented individuals into plant science.
- Ph.D. training: Need for 4-year Ph.D. with lab rotation
 - Proposal for 2+2 university-institute Ph.D. programmes
 - Desire to recruit from EU where there is a supply of suitably trained undergraduates
- Need for training in biometrics, genetics and plant breeding
- Need for additional support for crop-based training especially crop physiology and breeding

Funding

- Consistent concern about fragmentation and lack of coherent strategy amongst major funders
- Longer-term funding needed for some projects, especially crop plants
- Funding mechanisms should encourage collaboration and multidisciplinarity

Barriers

- Public perceptions
- Fragmentation amongst funders militates against coherent strategy
 - Most concern over BBSRC, Defra, DFID with occasional mention of Levy Boards, NERC, FSA and ESRC. Surprisingly no explicit mention of SEERAD nor industry
 - Defra's Crop Genetic Improvement Networks are thought to be beneficial but not enough.
- Lack of long-term strategy for crop science
 - Lack of clear directions for 'market-pull' and retrenchment of multinationals
 - Crop research in BBSRC losing ground to 'more tractable' plant science with greater scientific rewards
- Problem of recruitment and career development for researchers in crop science
 - Need to revise ground rules for evaluating crop research.
 - Limited numbers of young scientists entering crop science

Facilities

Between 30 and 35 of the submissions included specific responses to the questions on importance of facilities, and 22 to 28 to the questions on current access (not all of these respondents gave answers for all the various facilities).

On the **importance** of facilities, nearly all those who answered rated all the facilities as at least fairly important. In particular, genomic resources and facilities, field experiments and data facilities were rated as critically or very important in the majority of responses. There was a wider spread of responses on the importance of climate change facilities: six respondents rated these as being of low or no importance.

On **current access** to the facilities, over 63% of those who answered rated access to genomic resources, genomic facilities, germplasm collections and field experiments as satisfactory or better.

However, the most frequent response was "poor" for access to proteomics, metabolomics, climate change and data facilities (see Table A4.1).

Importance	Genomics resources	Genomics facilities	Prote- omics	Metab- olomics	Germplasm collections	Field experiments	Climate change	Data
Critical	23	19	6	6	24	15	5	15
Very important	10	10	12	9	9	15	10	12
fairly important	0	6	12	14	1	1	9	3
Low	0	0	3	4	0	0	5	0
importance								
no importance	0	0	0	0	1	0	1	0
Total	33	35	33	33	35	31	30	30

Access	Genomics resources	Genomics facilities	Prote- omics	Metab- olomics	Germplasm collections	Field experiments	Climate change	Data
Excellent	1	2	1	0	0	0	0	0
Good	11	8	2	2	7	5	3	6
Satisfactory	5	9	7	7	11	10	7	5
Poor	9	8	14	16	6	9	11	13
Very poor	1	1	1	1	0	0	1	1
Total	27	28	25	26	24	24	22	25

Mechanisms

Current structure of the UK crop science research community

- Approx. 70% of those who commented on balance of research between universities and research institutes thought that it was about right in terms of funding and focus, 30% did not
- There is a need for greater strategic co-ordination and collaboration between research institutes and universities, and less competition
- Need to sustain/increase critical mass
- Need higher end-user relevance and to work more with stakeholders and industry
- Need multidisciplinary projects
- Need to strengthen crop-based research
- Funding bodies need greater strategic integration and need to collaborate
- Limited number of young scientists with crop-based training.

Mechanisms for the support of UK crop science research

- Longer term (more than 3 years) and larger funds are needed for some projects, especially for crop plants
- Need greater co-ordination of funding bodies and long-term strategy.
- Need to fund transfer of knowledge and technologies from model plants to crop species
- Seen as unfair that projects on model species are judged on science excellence, while projects on crop plants are judged on science excellence *and* relevance
- Funding mechanisms should encourage collaboration
- General support to continue with responsive mode funding

- CSG funding appropriate/important for crop science
- Remit and membership of committees should be reconsidered

Mechanisms for the support of international research in crop science

- Few opportunities for international collaboration outside the EU
- EU funding has been good for developing collaborations/networks
- EU funding hard to get due to need for cross-country networks
- Limited opportunities for crop science under Framework 6
- DFID funding declining for crop science
- Need strategy for EU/international funding.

Mechanisms for the support of research training for UK crop science research

- Hard to obtain money for studentships since loss of MAFF funding
- Need more funding for crop based training, especially plant physiology and breeding
- Limited number of young scientists entering crop science. Need to encourage more to enter field
- Need to provide long-term career paths for crop scientists. Short-term contracts for post-docs are not helpful
- Career prospects are poor for crop scientists compared to those working on model species.
- 3 year PhDs are not long enough for crop based research.

Current level of BBSRC funding

response	number of replies	%
Too low	26	34
About right	8	11
Too high	0	0
Comment only No response	17 25	55
Total	76	

Table A4.2: responses on level of funding

Among those who replied specifically, 20 responded that the balance between crop research and plant science should be moved towards crops.

Further comments

- Need investment to translate technology and methods from model to agricultural systems
- Current levels of funding will not address stated priorities
- Investment needs co-ordination and strategy across funding bodies
- Investment from industry is low
- Important that BBSRC contributes to public debate on issues related to crop science.

Annex 5: Principal documents consulted by the panel during the review

BBSRC

Bioscience for Society: A Ten-Year Vision "Towards Predictive Biology". BBSRC (2003) *Review of BBSRC-Funded Research Relevant to Sustainable Agriculture.* BBSRC (2002) *World Class Bioscience: Strategic Plan 2003-2008.* BBSRC (2003)

BBSRC Institutes

Strategic plans

IACR Strategic Plan 2000-2005. Rothamsted Experimental Station (2001) IGER Strategic Plan 2001-2005. BBSRC-IGER (2001) IGER Innovations No 7. BBSRC-IGER (2003) John Innes Centre Corporate Plan 2001-2006. JIC (2001) New Fields: A vision for IGER's Science Strategy 2002-2008. IGER (2002)

Annual reports

Horticulture Research International Annual Report and Accounts Year ending 31 March 2002. Horticulture Research International (2002)

John Innes Centre and Sainsbury Laboratory Annual Report 2001. JIC (2001) IACR Annual Report 2001-2002. IACR (2002) IGER Annual Report and Accounts for 2002. IGER (2003)

Institute Assessment Exercise Visiting Group Reports (Confidential to BBSRC Council only)

Report of the Visiting Group to Horticulture Research International, 2001 Report of the Visiting Group to Institute of Arable Crops Research, 2001 Report of the Visiting Group to Institute of Grassland and Environmental Research, 2001 Report of the Visiting Group to The John Innes Centre, 2001 Report of the Visiting Group to Silsoe Research Institute, 2001

DEFRA

BioHybrids International Ltd, ADAS Consulting Ltd The Role of Future Public Research Investment in the Genetic Improvement of UK Grown Crops. DEFRA (2002)
Delivering the evidence: Defra's Science and Innovation Strategy 2003-06. DEFRA (2003)
Non-Food Crops Strategy. Defra draft consultation document, DEFRA (March 2004)
Our Strategy 2003-06. DEFRA (2003)

SEERAD

SEERAD Strategy for Agricultural, Biological and Related Research 1999-2003 (1999) SEERAD Programme of Agricultural, Biological and Related Research 2002-2003 (2002)

INTERNATIONAL

- Hervieu, B., Flament, J-C, de Jouvenel, H. INRA 2020: *Alimentation, Agriculture, Environnement: une prospective pour la recherche.* (2003)
- Microbial genomic sequencing: perspectives of the American Phytopathological Society. American Phytopathological Society (2003)

http://www.apsnet.org/media/ps/MicrobialGenomicsSeqFinal03.pdf

- Roadmap for Biomass Technologies in the United States. Biomass Research and Development Technical Advisory Committee (2002)
- Rosegrant, M. W., Paisner, M. S., Meijer, S. & Witcover, J. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*. International Food Policy Research Institute, Washington, DC (2001)

- Serageldin, I & Persley GJ. Promethean Science: Agricultural Biotechnology, the Environment, and the Poor. Consultative Group on International Agricultural Research, Washington, DC (2000)
- The Use of Genetically Modified Crops in Developing Countries. Nuffield Council on Bioethics (2002)
- Unlocking genetic diversity in crops for the resource-poor: Annual Workplan and Budget 2004. Consultative Group on International Agricultural Research, Washington, DC (2003) <u>http://www.genesforcrops.org</u>
- Vision for Bioenergy & Biobased Products in the United States: Biomass Research and Development Technical Advisory Committee (2002)

INDUSTRY

Agricultural Biotechnology in Europe. *Future Developments in Crop Biotechnology*. Issue Paper no 6. (2003)

Biotech 2020: Crop Biotechnology in the World of 2020: BCPC (2003)

CHARITIES

Gatsby Plant Science Review, Sept 2002. The Gatsby Charitable Foundation (2002)

MISCELLANEOUS

- Hillman, J. R. Report of the Director: SCRI Annual Report 2001-2002, pp. 12-59. Scottish Crop Research Institute (2003)
- Jamieson, B. et al. Skills Audit of Horticultural R & D: Report to the National Horticultural Forum.(2003)
- Prospecting Bioscience for the Future of Non-Food Uses of Crops. Institute of Innovation Research (2004)

GM crops

Genetically modified crops: the ethical and social issues. Nuffield Council on Bioethics (1999) Genetically modified foods & health: a second interim statement. British Medical Association, Board of Science and Education (March 2004)

UK Government reports on GM crops

Prime Minister's Strategy Unit Report (July 2003): *Field Work: Weighing up the Costs and Benefits* of GM crops <u>http://www.strategy.gov.uk/output/Page3673.asp</u>

GM Science Review: First Report (July 2003)

- GM Science Review: Second Report (January 2004) http://www.gmsciencedebate.org.uk/report/default.htm
- GM Nation? The findings of the public debate (September 2003) http://www.gmnation.org/docs/gmnation_finalreport.pdf

The GM Dialogue: Government response (March 2004) http://www.defra.gov.uk/environment/gm/debate/pdf/gmdialogue-response.pdf

Annex 6: Abbreviations

BAC	bacterial artificial chromosome
BBSRC	Biotechnology and Biological Sciences Research Council
BPC	British Potato Council
CGIAR	Consultative Group on International Agricultural Research
CSG	Core Strategic Grant (used to support long-term science in BBSRC institutes)
CRIC	ESRC Centre for Research on Innovation and Competition
DARDNI	Department of Agriculture and Rural Development, N. Ireland
Defra	Department for Environment, Food and Rural Affairs
DFID	Department for International Development
ESRC	Economic and Social Research Council
EU	European Union
FSA	Food Standards Agency
Gatsby	Gatsby Charitable Trust
GM	Genetically modified
HDC	Horticultural Development Council
HGCA	Home Grown Cereals Authority
HRI	Horticulture Research International
IFR	Institute of Food Research
IGER	Institute of Grassland and Environmental Research
IGF	Investigating Gene Function (BBSRC funding initiative in genomics)
INRA	Institut National de la Recherche Agronomique
IOIR	Institute of Innovation Research, University of Manchester
JIC	John Innes Centre
NERC	Natural Environment Research Council
NSF	US National Science Foundation
RRes	Rothamsted Research
SCRI	Scottish Crop Research Institute
SEERAD	Scottish Executive Environment and Rural Affairs Department.
SRI	Silsoe Research Institute