STRATEGIC RESEARCH FOR THE SCOTTISH GOVERNMENT: ENVIRONMENT BIOLOGY AND AGRICULTURE

Programme 1

Profitable and Sustainable Agriculture - Plants

Progress Report
1 April 2006 to 31 March 2008

Programme Co-ordinator
Professor Howard V. Davies

PROGRESS AT PROGRAMME LEVEL

Summary

Programme 1: Sustainable and Profitable Agriculture-Plants, remains on course to deliver the research commissioned by RERAD in line with the major objectives and outputs described in its Research Strategy Document (2006-2011).

Specific examples of key outputs for the reporting period include:

- A DNA marker for a barley grain component which produces undesirable properties in Scotch whisky is now accepted as an essential tool in barley breeding by the industry.
- Major progress has been made in the development of diagnostics for key pests and pathogens of potato and fruit. The diagnostics are being incorporated into industry and statutory testing procedures.
- Novel components which contribute to potato flavour have been identified.
- Specific components of fruit have been shown to inhibit the multiplication of specific cancer cells in laboratory tests.
- Improved disease forecasting, risk assessment and decision tools for barley crop management have been developed.
- Fourteen reference Scottish landscapes have been defined and characterised to provide historical baselines and comparators for new research on sustainable systems. Prototype models and decision-support tools have been developed to improve the ways in which specific ecosystems might be managed.
- The team has delivered more than 2000 knowledge transfer activities to a range of stakeholders including more than 150 refereed publications

Significant progress has been made in linking biological, ecological and environmental aspects of the Programme with economic studies which has laid a strong foundation for the delivery of more integrated approaches both to the Programme Work Package elements and to the delivery of Cross-Cutting Themes.

Value has been added to RERAD's Programme through national and international collaborations and from external funding for research and development from a wide range of sources (for example the European Union, BBSRC, Defra, LINK schemes, Levy Boards, the Generation Challenge Programme, the International Potato Centre (CIP), Rainbow Seed Fund investment the Food Standards Agency, Scottish Enterprise, Scottish Natural Heritage and industry. This amounted to ca. £10 million between 2006-2008 (scientific grants, commercial grants, consultancies).

While some mature research areas have been wound down, new appointments have also been made to further strengthen research capabilities and collaborations in high priority areas and provide the flexibility to deal with a range of emerging research questions. The availability of Scottish Government funding to purchase a new farm near SCRI has opened up possibilities for further cross-institute and cross-programme collaborations on longer term aspects of sustainability.

Programme overview

Headline developments

Central to the Programme are multidisciplinary teams of research scientists which use state-of-the-art approaches and technologies to address complex biological and environmental issues which are relevant to a wide range of end users, including policy makers, food manufacturers and marketers, farmers and land users. Specific examples of key outputs for the mid term report include:

- A DNA marker for a barley grain component which produces undesirable properties in Scotch whisky is now accepted as an essential tool in barley breeding by the industry.
- The most comprehensive genetic map of barley to date has been produced. It has located over 5,000 known genes and also incorporates information on gene expression levels.
- Candidate gene loci influencing plant development have been identified for a number of barley morphological mutants.
- New evidence has been found that infection of seed by two key pathogens of barley (*Rhynchosporium secalis* and *Ramularia collo-cygni)* represents a more important source of disease than was previously acknowledged. This has implications for disease control.
- A novel quantitative assay of caspase activities has been developed which will help to identify potential varietal resistance to *Rhynchosporium secalis*.
- A new modelling framework has shown that that manipulation of host heterogeneity can have a marked impact on emerging patterns of pathogen effectiveness.
- .A new aggressive genotype (named 13_A2) of the late blight causing organism *Phytophthora. infestans* (*P. infestans*) is becoming increasingly abundant and displacing existing populations in Scotland and across Great Britain.
- Protein signatures have been identified on a number of proteins produced by *P. infestans* which may interact with plant cells to manipulate host resistance.
- Through analysis of the genome sequence, *Pectobacterium* has been identified on non-potato wild species in the environment, raising questions on sources contamination for tubers.
- Two potato genes involved in basal resistance to viruses have been isolated and characterised.
- Novel resistances to a range of potato pathogens, including *Pectobacterium*, PVY and *P. infestans,* have been identified in *S. phureja*.
- The Commonwealth Potato Collection (CPC) has been increased by almost 200 accessions, including eight additional wild species.
- Major progress has been made in the development of diagnostics for key pests and pathogens of potato including potato leaf roll virus, potato cyst nematode and late blight. The diagnostics are being incorporated into industry and statutory testing procedures.
- Genotyping of the virus transmitting aphid *Myzus persicae* has improved methods of monitoring the appearance and movement of pesticide resistant populations.
- Compounds which help define the novel flavour of *Solanum phureja* potatoes have been identified and a gene isolated which controls the production of one of these compounds.

- A raspberry gene known as gene *H* has been confirmed as being associated with the fungal diseases of raspberry cane.
- Fractionated extracts of raspberry fruits enriched in compounds known as polyphenols, were shown to inhibit the multiplication of specific cancer cells in laboratory tests and to help prevent against damage to DNA.
- A quarantine inventory database has been developed and implemented in the statutory production of certified soft fruit nuclear stock. The Programme has provided the industry with high health plants of *Rubus* and *Ribes* for propagation, as the sole source of nuclear stock of soft fruit in the UK.
- Fourteen reference Scottish landscapes have been defined and characterised to provide historical baselines and comparators for new research on sustainable systems. Prototype models and decision-support tools have been developed to improve the ways in which specific ecosystems might be managed. The areas have diverged over time, in terms of the crops grown in them, and each area has taken on more crops, showing arable/grass agriculture has become more diverse over the last 25 years.
- A major baseline study of arable/grass agriculture has shown factors such as biodiversity and external impacts (for example carbon footprint) are more strongly determined by crop management (for example commodity, integrated, organic) than by location in East Scotland. In all forms of management, nitrogen fertiliser is responsible for the largest environmental 'footprint'.
- At the 'field scale', new techniques for assessing how robust soils are in terms of recovering from negative influences were successfully tested across Scotland. Approaches for monitoring biodiversity were also developed.

Added value through collaborations, interactions and external funding

External funding, collaborations and interactions relate to all components of Programme 1 (genetics, pathology, sustainable crop systems, and KT activities) and its associated required outputs. Value has been added to the RERAD commissioned research through research and development commissioned by a wide range of funding sources. Ongoing funding is supplied by RERAD (competitive research calls), the European Union (Framework Programme 6 and 7), through the European Research Area Network (ERA-net), European Marie Curie Fellowships, COST and Concerted Actions, the BBSRC (Crop Science Initiative), DEFRA and Agri-food, Arable and Horticulture LINK schemes, Generation Challenge Programme, The Royal Society, the International Potato Centre (CIP), INRA (France), Rainbow Seed Fund investment, the Agricultural and Horticultural Research Board (via levy bodies such as the Potato Council Ltd. Home Grown Cereals Authority (HGCA) and the Horticultural Development Council [HDC],) the Food Standards Agency, Scottish Enterprise (Proof of Concept), Chest Heart and Stroke Foundation and Scottish Natural Heritage. Industrial funding, which is dealt with by the business arms of the MRPs is significant and relevant in terms of knowledge, technology and materials transfers to end user communities. There is a significant number of other interactions with national and international bodies and academic centres which provide obvious synergy with the Programme objectives.

Examples of cross linkage (work packages, MRPs, programmes)

Cross-WP: Commodity-based genetics and pathology work packages are linked through research on host-pathogen interactions and resistance mechanisms. They also share common technological approaches and platforms in addition to mathematical and bioinformatics capabilities.

Links to WP 1.7: Genetics work packages (1.1, 1.2) link to WP 1.7 in characterising crop and other plant traits for sustainable systems (for example varieties and mutant lines for variation in drought stress and nutrient use efficiencies). The potato pathology work (1.5) package links with WP 1.7 through studies on the ecology of bacteria plant (Pectobacterium) and animal/human (*E. coli* and *Salmonella*) pathogens on plants (with objectives straddling both work packages). The links between soil health, weed community dynamics, insect herbivory and environmental pathology are being explored in association with WP 1.4.

Cross-MRP: There has been significant cross MRP interaction on the development of CCT strategies. In addition, SCRI and SAC have an MOU to use a critical mass partnership for improving business efficiency and business growth through exploration of joint funding and research/knowledge transfer opportunities. Key areas identified relevant to RERAD include agro-ecology, soils, disease and pest management and economics. There are also shared resources and expertise with MRI on bacterial pathogens; joint funding proposals have been formulated. SCRI works closely with SAC on KT events, using SAC's proven track record in KT to the farming community. There is MLURI and SAC representation on the Programme 1 Advisory Group.

Cross-Programme: There is Programme 1 representation on the Programme 3 Advisory Group and vice versa. In Programme 3 (WPs 3.2 and 3.3) the development of methodologies indicating soil status has been synergistic with the development and testing of biophysical indicators in WP 1.7. The multi-attribute decision model for soil status, developed in 3.2/3.3 will be used in subsequent 1.7 field experiments as one of the main indicator types that will be used to assess the effects of environment and farming practice. WPs 1.7 and 3.3 share access to field sites at SCRI and SAC (long-term organic rotations trial, tillage trial) and carry out complementary sampling programmes. Information from the baseline study and field experimentation programme in WP 1.7 feeds directly into bio-economic farm scale, landscape and catchment modelling taking place in WP 3.1. The research is designed to act as a means to allow the mechanistic (often organism-scale) research in WP 1.7 and WP 2.5 in Programme 2 to be scaled up to farm, landscape and catchment scales. Thus there is a link between 1.7 and WP 2.5 (dairy and upland system modelling). Links exist between WPs 1.5 and 2.2, where genomic resources and expertise are being shared.

Table 1. Knowledge exchange activity summary.

Audience		**No.**
Activity		
• Explanation/examples		
Policy		
Consultation body/policy group		
• Representation on advisory/policy groups		38
Workshop/conference (not published)		
• Includes high profile visitors or visits		4
Contributions to policy formulation or development		
• Consultation responses (Europe, UK, Scotland, NGOs and local authorities)		2
• MSPs and parliament		0
• Policy briefings/reports (Europe, UK, Scotland, NGOs and local authorities)		0
Advice to regulators and implementers		
• for example SEPA, SNH, FSA, Chief Vet. etc		1
Public		
News releases		426
Popular articles		8
Website info		2
Training/education and public awareness		
• Schools, colleges etc		141
Publicity material		6
Event for the public		
• Public science events for example festivals		14
• Science lecture		9
• Open day		1
Commercial		
Intellectual property		
• Income from IP	£788,000	
• Spin out companies		0
Technology transfer		
• Licences, patents and plant variety rights		48
• Commercial grants	£1,686,705	
• Consulting income	£402,000	

Scientists		
Scientific publications		
• Peer reviewed		154
• Other reports/publications		243
Invited lecture/presentation		
• Conference contributions		294
Science poster		
• Conference contributions		108
Website info		14
Publicity material		4
Workshop/conference (not published)		158
Scientific grants	£8,356,537	

Programme Specific Stakeholders	
News releases	367
Trade/industry talks	151
Website info	0
Workshop/conference (not published)	3
Open day/demo/site visit	
• Agricultural show, farmer event etc	109
• Responding to requests for advice	25
Industry publication	24
Trade/industry poster	9
Publicity material	0
Stakeholder consultative group (member of)	2

Programme objectives

Programme objective 1: Genetics for sustainability

Aim: To identify and exploit novelty in genetic resources for the benefit of end-users.

Examples of significant progress and successes include:

Barley:

- An extensive germplasm collection, ranging from elite material through landraces to wild species and novel mutant populations, has been assembled to underpin high resolution genetic studies. This will facilitate including sequence-based allele mining using mapped barley genes.
- Over 5,000 barley genes have been genetically mapped across the entire barley genome, allowing detailed and rapid comparisons with model genomes. Over 9 million genotypic data points have been collected detailing variation of specific genes.
- Extreme alleles of *c.* 1000 genes that affect morphological, disease resistance and developmental processes have been placed on the barley gene map.
- In excess of 500,000 phenotypic data points from National List and Recommended List trials from 1988 to 2005 have been collated into a computable format. This can now be linked to genetic parameters.
- Marker trait packages have been developed for yield (flowering and maturity), quality (epiheterodendrin and beta-glucan) and disease resistance characters (mildew, rhynchosporium rusts and viruses).
- Genome-wide patterns of gene transcript abundance have been established in a segregating doubled haploid population generating 1000's of gene based 'transcript derived markers' and genome wide 'expression QTLs' (eQTLs).
- Alternative splicing of gene transcripts has been shown to affect a broad range of gene products after various abiotic stresses have been imposed suggesting that this may be a major point of post-transcriptional gene regulation. An innovative new approach for assessing the impact of alternative splicing after imposing various abiotic stresses on barley has been developed.
- An efficient protocol for barley transformation and a suite of relevant Gateway vectors has been implemented.
- Protocols have been developed for the high-throughput phenotyping of beta-glucan, antioxidant and lipid content in barley varieties.
- The *sdw1* semi-dwarf gene has been characterized and is associated with later heading and maturity.
- Two important factors have been indentified which affect the sustainability of the barley to whisky/beer sectors supply chain. First, the quality of communication along the chain is crucial. Second, the strength of the relationship provides commercial reward, which may range from direct improvement in revenues or costs, to indirect benefits such as greater reliability or flexibility during difficult market conditions

Potato:

- A further 200 accessions, including 8 new species, have been added to the Commonwealth Potato Collection (CPC) taking the total to 1500. The collection continues to be rejuvenated under stringent European quarantine standards for plant health.
- Molecular analysis has clarified the origin of the cultivated potato informing utilisation of the collection.
- Resistance to potato cyst nematode (PCN [*G.pallida*]) was confirmed in 11 accessions.
- Genetic analysis of yield, agronomic and quality trait data identified a total of 39 Quantitative Trait Loci (QTL).
- Markers diagnostic for late blight and PCN resistance have been found and candidate host resistance (R genes) for blight resistance identified using microarrays.
- Approaches to more efficient selection for potato virus Y (PVY) resistance have been identified.
- The diploid *Solanum phureja* cultivar Mayan Gold was launched by commercial collaborators Greenvale AP in 2006 with significant UK wide press coverage. It was the first Phureja to be commercialised in Europe.
- Phureja is well differentiated in terms of quality and disease resistance traits and is an excellent model for strategic, comparative studies and gene discovery.
- Evidence has accumulated that Umami compounds (which drive the 5th flavour sense) are considerably higher in Phureja compared with Tuberosum and contribute to flavour differentials.
- Microarray analysis has identified a specific sesquiterpene synthase as a strong candidate for a gene controlling cooked potato flavour and aroma, and a pectin methyl esterase in the control of texture after cooking.
- Significant differences in phosphorus use efficiency have been identified in specific germplasm and chromosomal regions affecting this property have been identified for further investigation.
- Germplasm with low acrylamide producing potential has been identified.

Soft fruit:

- The raspberry (*Rubus)* and blackcurrant (*Ribes)* mapping populations have been doubled and Nuclear Stocks tested for viruses and fungal pathogens.
- The first *Ribes* genetic linkage map has been completed, and the *Rubus* map has been enhanced with new functional and gene-based markers. A DNA-based marker linked to gall mite resistance in *Ribes* is in the final stages of validation and Quantitative Trait Loci (QTLs) identified in *Rubus* and *Ribes* for a range of developmental and fruit quality traits for example anthocyanin content, bud break, flowering.
- Metabolomics has been established for rapid and large scale multiple chemotyping of berry populations across different environmental conditions and a *Ribes* population has been chemotyped.
- Model systems indicate the potential health benefits of fruit polyphenolics (for example anticancer potential, impact on cardiovascular health and digestion).

Uptake of outputs

The practical application of genetics for sustainability in breeding requires timely uptake and is by nature a long term process. However, already in WP 1.1 a DNA marker has been developed for a barley grain component producing undesirable properties in Scotch whisky and which is now accepted as an essential tool in barley breeding by the industry. Links have been forged with the distilling community to ensure that the outputs address improvement of the processing requirements of barley. A specific organisation, UK Barley Network, has been created as a major channel for knowledge transfer amongst the genetics, breeding and end-user communities. The relevance of the RERAD funded barley work is demonstrated by the increasing numbers of UK and continental barley breeders that have consulted SCRI over the past two years. Similarly, the development of commercial varieties of potato and fruit through appropriate partnerships is testimony to the continued relevance and uptake of RERAD funded crop genetics. The summary of key outputs achieved to date is evidence of the national and international quality and relevance of the research. Many of the outputs will impact on our capacity to enhance breeding efficiency and effectiveness for a range of commodities and for a range of end users and markets, including those creating wealth, health and greener approaches which reduce environmental footprints. Already the Programme is addressing issues relevant to the CCTs for example water and nutrient use efficiency. KT and KE field events have been organised by SAC (Success Through Knowledge Campaign), SAC+SCRI+SSCR+levy bodies for example Potatoes in Practice, Cereal Solutions, Fruit for The Future. Programme-related information is presented at end user-based meetings organized by commercial sponsors. Technical notes embracing economic and sustainable production issues have been delivered to growers for example Barley Disease Control (March 2008). ISBN 1 85482 867 3 Authors Simon Oxley, Fiona Burnett.

Programme objective 2: Plant pathology for sustainable crop production

Aim: To develop and deliver tools which improve plant health.

Examples of significant progress and successes include:

Barley:

- Demonstration of the importance of seed infection in causing the early disease epidemics of rhynchosporium and ramularia. Microsatellite marker methods have been developed for identifying specific *Rhynchosporium secalis (R.secalis)* isolates.
- *R. secalis* spores can be detected throughout the year, alongside the presence of the pathogen in the seed, developing plants and in trash, leading to a wider range of potential infection threats to a crop.
- A significant reduction in *R secalis* infection occurs in tall genotypes with prostrate leaves, compared with short or erect-leaved genotypes.
- A model has indicated that characteristics such as the ability of the plant to increase its photosynthetic rate to compensate for loss of green area to disease, and the rate of disease-induced leaf senescence have the greatest impact on disease tolerance.
- With *R.secalis* a combination of specific chemical elicitors and reduced rates of fungicide application optimises host resistance.

- There is a clear influence of genotype on the expression of induced resistance, but no association between the resistance rating of a variety and its ability to express induced resistance.
- Varietal mixtures of spring barley are superior to single varieties in several aspects including stability of yield and quality, suitability for use under varied soil cultivation methods and under low input situations.
- A new modelling framework has shown that manipulation of host heterogeneity can have a marked impact on emerging patterns of pathogen effectiveness.

Potato:

- Scottish isolates of *Phytophthora infestans (P.infestans*), the organism causing late blight show only three forms of a protein which interacts with host defence. The current *P. infestans* population is dominated by isolates belonging to one abundant genotype of *P. infestans.* There is evidence for reduced host resistance to this genotype.
- An approach to sampling late blight outbreaks and use of DNA markers to determine the source of the outbreak in *P. infestans* has been established and used practically in over 400 blight outbreaks sampled across GB.
- The Programme has contributed to the international consortium sequencing the *P. infestans* genome and has identified hundreds of proteins which may interact with plant cells to manipulate host defences.
- The complete genome sequence of the bacterium (Pectobacterium) causing blackleg disease has been completed with RERAD funding contribution and has already revealed a mechanism allowing the bacterium to live on non-host plant roots. The wider environment may act as a reservoir for potato tuber contamination.
- Specific lines of Phureja have naturally high levels of a specific protein previously shown to be important in bacterial resistance. Other proteins known as caspases, a component of the general defence response against microbial pathogens, have been found in potato. Caspase levels have been correlated with resistance to both pathogen and physical/chemical stresses
- Specific proteins from the potato cyst nematode (*G. pallida)*, suppress plant defences assisting this pathogen to infect potato.
- The behaviour of the virus-spreading aphid *M. persicae* can be altered by the crops it encounters and is influenced by its previous source of plant food prior to making that choice.
- Diagnostic tests have been developed for (a) the skinspot-causing organism Spongospora; (b) PCN (*G. pallida)* specific types of the aphid species *M. persicae.* A standardised test for the spread of Potato Leaf Roll Virus within aphid vectors has been developed to provide data for climate change studies on risks to plant health.
- Host defence genes protecting against virus infection have been identified together with PVY resistant accessions of Phureja. The potato IVR and RdRp1 genes, both involved in basal resistance to viruses, have been isolated and characterised.
- Infectious reporter clones have been developed to investigate the long-distance movement and transmission by vector of potato mop-top virus. Studies on long-distance movement have revealed that the virus genome moves as particles and as ribonucleoprotein complexes which has implications for transmission by Spongospora.

- Sequencing of *Spongospora* sporeballs has shown that two individual (ribo)types (Types I and II) are present in Scotland, which is different to that in other countries and type II is most common. The ribotypes are not mixed within single disease lesions but can be found in the same field.

Soft fruit:

- New sources of aphid resistance have been found in *Rubus* and are being introgressed into enhanced raspberry germplasm.
- Vine weevils are an increasing pest in protected soft fruit, and have been found to promote aphid populations in a variety-specific manner, indirectly promoting an increase in aphid populations and compromising multigenic resistance.
- Sustainable crop protection options have optimised the efficacy of pest resistance genes and natural enemies to reduce pest numbers and virus problems and extend the durability of plant resistance.
- Resistance-breaking isolates of RBDV were found in a local plantation of cv. Glen Ample, disproving the reported field resistance.
- New diagnostics have been developed for Phytophthora (causes raspberry root rot), black raspberry necrosis virus (BRNV), raspberry leaf spot virus (RLSV) and raspberry leaf mottle virus (RLMV). Two new viruses, *Rubus* chlorotic mottle virus (RuCMV) and raspberry green leaf blotch virus (RGLBV), have been identified locally.
- Gene *H*, associated with resistance to cane botrytis and spur blight in *Rubus* has been mapped and potential candidate genes identified.
- Extended cropping seasons within the micro- and macroclimate of polytunnels provide green bridges, producing increased pest pressure on *Rubus*,

Uptake of outputs

Impact and uptake by the academic community has been realised through publications, significant national and international collaborations and competitive grant income. The uptake of the strategic elements is usually longer term but the Programme has already identified novel sources of host pest and disease and some of the genes underpinning these. Markers already identified are being deployed in breeding programmes. Furthermore, the outputs already have relevance to the broader issues of changing cropping systems and environments, climate change and sustainability for example protected cropping, emerging pest and disease issues. There is continued need to horizon scan solutions to emerging pest and disease problems and the need for more durable resistance (links to the Genetics for Sustainability required output.). This requires relevant interactions between work packages.

Examples of practical relevance include:

1. New sampling and diagnostic tools for pests and diseases for example potato skinspot, potato cyst nematode, *Phytophthora* (fruit and potato), potato and raspberry aphids, have been developed with, and are being used by, organisations including levy bodies (PC Ltd) and SASA.
2. Development of Comprehensive Standard Operating Procedures (SOP's) and refinement of Quarantine inventory databases in the statutory production of certified soft fruit nuclear stock.
3. Enhanced web-based databases accessible by industry for example (a) HGCA incorporation of decision tools into the web based RL plus tool which is sent to all

levy payers with the recommended List.; (b) Web-based information (FRUITGATEWAY) for growers on pests and disease of soft fruit.

4. KT and KE: Field events organised by SAC (Success Through Knowledge Campaign), SACI+SCRI+ SSCR+levy bodies for example Potatoes in Practice. Technical notes embracing economic and sustainable production issues; Use of sampling tools on demonstration farms.

Programme objective 3: Designing crops for sustainable production

Aim: To develop and deliver tools and knowledge to improve crop management in an environmentally-sustainable way.

Several work packages are contributing, directly or indirectly, to this objective, through, for example, the development of pest and disease resistant crops, crops which can take up nutrients more effectively, and by improving our ability to understand the spread of disease. However, within Programme 1, Programme Objective 3 is mainly the responsibility of WP 1.7 which is developing tools and models to assist in improving crop management within the context of developing more sustainable cropping systems (optimising efficient production whilst maintaining a desirable level of biodiversity in the field and minimal external negative impact). The work package was formally commissioned some time after the others in Programme 1 because the research team was required to respond to some significant reviewer's concerns before the work programme could be agreed. The commissioning letter was received at SCRI on 15 November 2006.

Examples of significant progress and successes include:

- A major survey of arable/grass farming in Scotland showed that it is more diverse now than 25 years ago both in terms of the number of crops and the proportional area sown with crops. Other important findings from the survey are:

  - The net change estimated in solar energy capture (and by implication carbon uptake) varied in the Scottish sites studied (for example by up to +10%). Uncertainties due to set aside and certain other crop types were of similar size to these changes.
  - The main conclusion is that arable/grass farming in Scotland has adapted over time to become, in total, more diverse.
  - Farm types (commodity, organic, integrated) were distinguished in multivariate analysis by agronomic and infrastructural variables; organic and commodity were clearly separated while integrated overlapped with both the other types.
  - The farm types differed in arable vegetation, not only in abundance but in species complement and diversity.
  - The variation among field types was dominated by nitrogen inputs, whether applied as inorganic or organic nitrogen. This was the single most important factor controlling carbon footprint per unit area in the arable/grass farms of east Scotland.
- A central framework for examining highly dynamic energy/carbon balances in highly disturbed arable-grass systems has been developed. This has links to an informal user interface, via the software *Dexi*, designed to allow interrogation of the model. Important sources of data for the model include:
  - The long established trial on organic rotations at SAC providing measures of nutrient cycling processes, soil biophysical properties, etc.

  - Experiments on physical manipulation (tillage) and carbon additions to soil at SCRI (plot scale) provide soil biophysical and microbial parameters, carbon content, vegetation, etc.
- Data on crop, pests and agronomy, from a previous arable survey on commodity farms in the 1990s (COIRE), have been transferred to electronic media for subsequent analysis.
- A wide range of *in situ* biophysical indicators has been developed and field tested to address for example seedbank and vegetation, arable food webs, soil and plant carbon and nutrients, soil microbial resilience, carbon transfers from crop plants to soil and their impact on soil microbial resilience and functioning.
- Using data from farm-based, historical cropping surveys in Scotland, a baseline study has shown that the contributors to carbon footprint ranked as follows: N > other fertiliser > tillage >pesticides.
- Potato ranks as the crop with the highest carbon footprint and legumes lowest, but the much larger areas sown to the intermediate cereals and rapeseed mean that these crops dominate the carbon footprint on a regional scale. Changes to the cereals will have to be brought about if the footprint is to be reduced.
- Weed-suppressive varieties could be used in reduced input systems that allow some coexistence of crop and weed, thereby reducing the footprint whilst supporting an active food web, with minimal yield loss. Cereal varieties grown without herbicides differed by up to 40% in their ability to suppress weed cover.
- Traits for phenology and architecture were identified in the field in terms of solar radiation capture and allocation of dry matter and nutrients between crop and weeds. Methods were developed to quantify the architecture of plants using sonic techniques.
- Definitive differences have been identified among crop varieties in nutrient use efficiency (for example in the proportion of N allocated to grain) and in rooting performance under stress conditions (for example soil compaction, drought).
- Work in cereal-legume intercrops has shown that inter-specific mixtures can increase resource use efficiency (biomass production per unit of nutrient uptake [land equivalent ratio]), can impact on losses of nitrogen by leaching and gaseous processes and, for the first time, has demonstrated carryover effects of nitrous oxide release from incorporation of legumes in the previous year.

Uptake of outputs

The system framework and biophysical indicator outputs have contributed to policy groups working on environmental surveillance and monitoring (Europe, Defra, RERAD). Work package staff are also involved in providing policy advice on soils, phosphorus use and organic farming to RERAD, Defra and others. A prototype decision support tool has been developed for policy with feedback received from government policy advisers. The first biophysical indicator was released for general usage: the *Visual Soil Structure Assessment* is an informative, simple test that has been developed with international collaboration. It gives a score to a spade of soil sampled in the field and is intended for advisors and farmers. This technique relates well to measured soil strength and porosity. It is an example of the way detailed knowledge of soil biophysics can be turned into an indicator that all stakeholders can use. Work package staff are in the process of summarising current knowledge on the role of the arable flora in sustaining crop systems, notably the trade offs between its ‘negative’ (the weed burden, hosts for pathogens) and ‘positive’ aspects (conservation, basis of the food web, nutrient mop-up). This is being developed with stakeholders (RSPB, LEAF, FWAG, Game Conservancy, etc.) and will be rolled out as a series of packages for layman and specialist that include recommendations for

best practice. *A* host of KTE events meant that research within WP 1.7 reached several thousand farmers, agronomists and representatives of industry, translating science into practice in topics such as fertilizer recommendation, rotation design, organic farming and variety recommended lists for cereals, oilseed rape, grass and legumes. The long-term crop rotation, organic amendment and tillage trials continue to provide an excellent platform for KTE events. With regard to the Cross Cutting Themes, WP1.7 is the primary source of knowledge of biodiversity in the arable-grass systems of the east of Scotland. It aims to develop prototype systems for sustainable agriculture, while the models of energy and matter cycles enable estimates and predictions of the effect of climate change on crops and their agronomy.

Programme forward look

Examples of opportunities and challenges have arisen through:

Challenges:

- The Cross Cutting Themes. The challenge has been to develop integrated Work Package, Programme and cross Programme strategies that can be used to evolve the science base to deal with these broader issues. CCT Champions have made good progress in respect.
- Staff restructuring within participating MRPs which has led to a re-focusing of effort in some areas. The details are provided in the work package reports. However, the overall impact on required outputs is minor. New appointments within participating MRPs are providing opportunities to strengthen research capabilities in the disciplines needed to deliver on the evolving Cross Cutting Themes and future outputs relevant to Government policy (smarter, greener, healthier and wealthier Scotland). These include the strengthening of research in microbial ecology, host-pathogen interactions, barley pathology, molecular plant breeding, plant nutrition, bioinformatics, resource use efficiency, mathematical biology and phytochemistry.
- Propositions for mergers between specific MRPs.

Opportunities:

- Opportunities have arisen through the launch of the plan for Scotland's first national food policy and the establishment of Scotland Food & Drink, an industry-led organisation with plans to create a food and drink industry worth £10 billion by 2017.
- The availability of Scottish Government funding to relocate SCRI's field experiment site from the Gourdie site to the Balruddery site and the transfer of land ownership. This opens up possibilities for further cross MRP, cross Programme and cross work package experiments on aspects of sustainability. Options are under discussion.
- Development of a formal MOU between SCRI and SAC to expand research capabilities in key areas (agro ecology, pathology, economics, soils, KT).
- Broader dialogue with the end user community in the focusing of research objectives for example the need for more marker trait packages in WP 1.1 rather than specific trait introgression into adapted genetic backgrounds.
- Propositions for mergers between specific MRPs.

Breakthroughs expected next year

Whilst these cannot always be predicted the following are indicative:

- Identify candidate genes influencing a range of barley developmental characters (grain shape, plant stature).
- Deploy the barley functional gene map to identify markers associated with economically important characters, which will result in the release of marker trait packages to the end-user community.
- A novel quantitative assay of caspase activities will be used to identify potential varietal resistance to *Rhynchosporium secalis.*
- Determination of the resistance of transgenic and *S. phureja* plants to isolates of *Dickeya* and *Ralstonia* (brown rot - through links with SASA).
- Determine the nature of novel extreme resistance to PVY in S. phureja and whether it operates against other PVY strains and other potyviruses.
- Determine the influence of crop systems surrounding potato crops on aphid vector pressure within the potato crop.
- Establish the role of α–copaene synthase in potato flavour and of pectin ethyl esterase and pectin acetyl esterase on texture.
- Validation of the PCR-based marker linked to gall mite resistance in *Ribes* will be completed and the marker will be fully deployed in segregating germplasm.
- New Taqman based protocols for the detection of *Phythophthora rubi* and *R. idaei* will be developed for use in the production of high health stocks.
- The development of robust IPDM strategies for soft fruit based on monitoring and trapping, together with the identification of novel sources of resistance.
- Develop a first estimate of field variables which most strongly prevent agriculture achieving the desired environmental and societal benefits desired.
- The external, environment impact of arable/grass agriculture (for example carbon footprint, solar/fossil ratios) will be estimated for the first time for specific fields and rotations representative of arable/grass farming systems in East Scotland, including a comparison of commodity, integrated and organic management.

Collaborative activities

Within Programme 1 we will continue to expand scientific collaborations between SAC, SCRI and MLURI, assessing for example the use of a newly acquired farm for long term sustainability studies. SCRI will continue collaborations with SAC on major KT events for example Potatoes in Practice and with SAC and MLURI in plans for Programme 1 stakeholder and policy days in 2009 (see Main Programme Level Events Section). SCRI, SAC and MLURI will increase the integration of field measurements at key experimental sites. In addition SAC, SCRI and the other MRP's are working together with the Scottish Government communications staff to organise press briefings with senior Ministers to illustrate the value of the RERAD-funded research programme. This has covered climate change (with inputs from Programme 1) and a food supply chain feature will be delivered in October 2008. Similar press days will be developed into 2009 and beyond. Cross Programme collaborations will expand for example links between WP1.7, WP 3.1 and 3.8 and there will a continued need to collaborate with all Programmes in developing the Cross Cutting themes and in the development of an integrated research programme relevant to the new RERAD Science Strategy. As would be expected, scientific collaborations will be expanded through the usual channels (MOUs with relevant third parties (for example HortResearch New Zealand), EU Framework Programme, International initiatives for example Potato Genome Sequencing; PCN genome

sequencing, consultancies). Staff working in the Programme already have an impressive range of national and international collaborations.

Main programme level events

The Programme will continue to host stakeholder events such as Fruit for the Future, Cereals Solutions, joint success through knowledge/HGCA events, Potatoes in Practice (the major UK potato event) and LEAF farm days. Cereal Solutions will expand in 2009 to include fuller representation of SAC's work at SCRI's Balruddery farm. The value of Programme 1 research will also feature at the 2008 SAC Outlook Conference and future SAC Environment Conferences (formerly SAC/SEPA Conferences). For the period 2008-2009 new priorities are being given to public audiences and policy makers/ government audiences. The Programme will continue to have representation at major public events such as The Royal Highland Show, Gardening Scotland etc. In 2009 we will also organise 2 specific Programme KT events. The first will be directed towards a range of stakeholders to showcase the quality of scientific achievements and relevance of the research outputs and to debate future research requirements. We propose that the second event is held in Edinburgh at Scottish Government offices to target, more specifically, individuals in policy units. We will also celebrate the International Year of the Potato through an International Symposium held in Dundee.

Wider impact on sustainable economic development

The Programme contributes to the major objectives of the Scottish Government in generating knowledge and products that contribute to a smarter, healthier, greener and wealthier nation. With regard to sustaining rural communities, food security and wealth creation the Programme's research objectives are as valid now as when the Programme was first commissioned. There are clear examples of where Programme 1 research relates to the central issues of sustainability, adaptation to climate change and biodiversity (use of and protection of). It is also clear that plant and crop based food and non-food production platforms have increased in global importance from both economic and societal perspectives. As an example of wealth creating. potential an independent assessment by DTZ Pieder of SCRI's research and breeding efforts to date (including pre-Programme 1 commissioning) indicated that every £1 of public money spent on research in this area produced a return of £14, The figure does not include any value or potential value derived from products, knowledge and knowledge transfer related to "environmental goods".

There will a be continued need to develop and deploy contemporary scientific knowledge and technologies to deliver next generation crop varieties, with improved yield, quality, nutritional profile, and pest/disease resistance under reduced inputs. These crops will need to be grown under sustainable cropping systems which reduce environmental footprints. Linkages between modelling and experimental work in WP 1.7 and WP 3.1 will continue the development of tools to help farmers and land managers to develop such cropping systems Programme 1 will continue to add value throughout the food chain.

The socio-economic components of the Programme will continue to explore and communicate opportunities and challenges for optimising economic returns. Programme 1 KT and KTE activities and partnerships will continue the timely distribution of information to stakeholders. SAC continues to use the RERAD-funded research to improve the advice that can be delivered as consultancy services across

the UK. The numbers of farmers subscribing to this have grown to over 7000 in 2007, ensuring that the competitiveness of these businesses is enhanced through contemporary information. The renaissance in agriculture and crop production in 2008 as a feature of food security issues has increased the demand for consultancy services appropriate to Programme 1. In addition, the interpretation of the SRDP and associated policies is an area of increasing practical demand from land-based industries keen to develop their businesses in a sustainable fashion. Furthermore, new and evolving Government policies in relation to food and drink in Scotland requires expert research information that provides a rational basis for policy implementation. This policy environment is key to sustaining economic development in the food supply chain in Scotland.

PROGRAMME AND WORK PACKAGE MANAGEMENT

The Programme 1 Advisory Group provides advice and guidance on the research (relevance, progress, forward look) and KT activities. Within the framework of the agreed Programme outputs the Group support the MRP Directors/CEOs and their Governing Bodies to ensure that the Programme activities are effectively co-ordinated. The Group, through dialogue with RERAD staff attending Programme Group meetings, also act as an important conduit for clarifying and commenting on policy areas at the Programme interface. The Programme 1 Co-ordinator organises the meetings and provides papers for discussion, comment and action. The Group meets biannually and at specified meetings has oral updates on science, KT, CCTs etc from work package leaders and others.

Programme Advisory Group Composition:

Four representatives from MRPs (SCRI, SAC, MLURI, BiOSS), one farmer (also levy board representative), one academic, RERAD observers (2 max.), Programme 1 Co-ordinator and Advisory Group Chair.

Terms of Reference:

- To monitor the progress of research and the effectiveness of interactions both within the Programme and with other SRG Research Programme.
- To advise the Director/CEO of the participating MRPs on the delivery of the Work Package objectives and outcomes - identifying risks to the research outcomes and advising the MRPs of appropriate remedial action.
- To advise the Director/CEO of the participating MRPs and the Programme Co-ordinator on the effectiveness of the delivery of matters relating to the Cross Cutting Themes.
- To advise and assist the Director/CEO of the participating MRPs and the Programme Co-ordinator on maximising output and identifying new opportunities for Programme level research and Knowledge Exchange and Transfer.
- To facilitate interactions with stakeholders, to identify opportunities to enhance interactions and to discuss problems as perceived by stakeholders.
- To agree an annual report for submission to the SRG and its SAP, summarising progress on all Programme activities including discussions with stakeholders.
- To advise and assist the Programme Co-ordinator in the organisation of Programme level workshops with end-users to discuss progress in the research and to identify new opportunities for future work.
- To participate in workshops, discussion groups, open days, etc where appropriate.

Work Package Advisory Group Composition:

The detailed research work of the work packages is assisted by interaction with appropriate Advisory Groups as follows:

WP 1.1 + 1.4 (joint): 3 academics, 3 end users, 1 MRP rep., 1 stakeholder rep.
WP 1.2 + 1.5 (joint): 2 academics, 6 end users.
WP 1.3: 1 MRP rep., 2 end users, 1 academic, 1 policy related (Defra).
WP 1.7: 1 academic, 3 farming groups (organic, LEAF, commodity), work package management group.

Terms of Reference for Work Package Advisory Groups:

- To advise on the appropriate direction of the work package research programme in the context of scientific excellence, end user relevance, sustainability, environmental and economic constraints.
- To advise on the communication and promotion of research conducted within the work packages across the appropriate sectors.
- To facilitate interactions between collaborating MRPs and the appropriate end user sectors to deliver more effective and relevant solutions to these sectors.
- To attend an annual review meeting and contribute to a brief written report.
- Minutes and proposed action points from advisory group meetings will be communicated to the Programme 1 Co-ordinator.
- Communication and promotion of research should occur through appropriate channels including the offices of Heads of Corporate Communications at the appropriate organisations.
- The Programme 1 Group maintains overall responsibility for agreeing and communicating the need for significant changes in direction and resource allocation to SEERAD.

Programme and Work Package Management:

The Programme 1 Co-ordinator provides the liaison channel with RERAD and works with WP leaders and staff from participating MRPs, (including CEOs and other Programme Co-ordinators where appropriate), to identify and resolve ongoing and emerging issues that will impact on the delivery of outputs for example effects of re-structuring and man power planning at MRPs. The challenge of Programme Co-ordination relates to the fact that several MRPs are involved with diverse funding sources and manpower requirements for strategic developments. These may not always align with specific Programme requirements.

Major Programme level KT events for example LEAF events, Potatoes in Practice, Cereal Solutions, Fruit Focus, Royal Highland Show etc are organised by communication experts at participating MRPs operating with scientists. Programme Group Chairs have met, together with Co-ordinators (and RERAD) to cross familiarise with required outputs and progress and to discuss strategy for example on CCTs. Similarly, a cross Programme event involving lead scientists, RERAD staff and guest speakers was organised in Aberdeen for cross familiarisation, to encourage further interactions and for initial horizon scanning on the next RERAD science strategy.

Progress within work packages is monitored via regular meetings between WP leaders and Principal Investigators, through discussions with the Programme Co-

ordinator, and through updates provided to the Programme Advisory Group. Progress, relevance and KT opportunities are also addressed through more formal meetings (annual) with WP Advisory Groups. Feedback is provided through minutes circulated by WP leaders which include action points from the events. The comments received from the WP advisory group meetings held to date have been very supportive and do not indicate the need for any significant changes in the work plan.