Management of genes and organisms in the environment

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The global summit in Johannesburg ensured that habitat protection and food security remained of international concern in 2002[1]. While interest is often attached to rainforests and coral reefs, the common arable soil and its biota are an essential part of the biosphere. If they cannot be sustained to yield food and raw materials in perpetuity, there is no possibility that other habitats can be left intact or restored. Locally, also, the choice is to exploit Scotland's fields to its detriment - "the land left dry as a rat-sucked swede[2]" - or to manage soil and its plant and animals with purpose to ensure their survival and productivity for millennia to come.

Disturbance is essential to the arable system. Hence, resilience – the ability of the system to reassert itself – is a most important quality. The scientific challenge is to define resilient states, because the arable soils and their associated plant and animal populations are surprisingly elusive. The controlling processes occur at small scales in fine soil pores, or are mediated by microscopic organisms, whose taxonomy and functions are often impossible to study outside the system. The new 'environment' theme at SCRI aims to probe these habitats using the most advanced technical and theoretical tools and to quantify resilient states towards which management can move the system. A crucial further contribution to define criteria for environmentally beneficial crop genotypes that confer resilience to the soil and food webs.

The Theme is organised into three inter-relating Programmes, concentrating on the plant and invertebrate food webs, soil-plant processes, host-parasite coevolution and the generic topics of bioinformatics and modelling. Plant genotype lies at the centre of each programme. We now profile one of the Programmes to illustrate how the science in Theme 3 links with other Themes at SCRI and with science and practice elsewhere. Longer articles follow, describing recent advances in probing soil processes, the arable seedbank, trait space, geneflow, and integrated pest management.

Co-evolution – the role and functioning of a new research programme The completely new programme – Host-Parasite Co-evolution - (?) is centred on interactions between plants and microbial pathogens, and nematode and arthropod (insects and mites) pathogens and pests, at the scale of field and ecosystem, rather than the molecular or genomic level. The main goal is not to determine the genetical or biochemical bases of host-parasite recognition but to predict the consequences of success and failure of host-parasite recognition in crops and natural ecosystems. Thus it complements the new Molecular Pathology (Plant-Pathogen Interactions) Programme in Theme 1. The two Programmes are now located in the same building, with the express purpose of maintaining, promoting and facilitating collaboration between them.

The 'raison d'etre' of 'Co-evolution', as the new Programme came quickly to be known, is the demand for 'sustainability' in modern agriculture. For sustainable agriculture to be successful, it will have to balance environmental and resource constraints with the overall food crop requirements of mankind. For the new programme, this essentially means maintaining crop yields while controlling diseases and pests and at the same time minimising or even eliminating the use of pesticides.

An important component of sustainable agriculture is host resistance to diseases and pests but one of the largest threats to pest such resistance is the ability of pests and parasites to overcome resistance, frequently with no prior warning. In natural ecosystems the co-evolution of hosts and their parasites generally leads to a durable and sustainable balance. Understanding this balance, which has genetic interaction with the environment at its centre, will lead to manipulation of the key interactions in favour of stability and resilience in a agricultural systems which favours the crop.

Not only do parasites cause selection for resistance within host populations, but also resistant hosts apply selection to parasite populations to overcome that resistance. These selection pressures depend upon genetic, spatial and temporal factors, the expression of each being modulated in turn by environmental factors. In crops, we have some control on all but the environmental effects on gene expression in the host but we have no control over the parasite populations except through the host on which they are dependent. By manipulating host genetics of host resistance we can study the effects of this dependency which will determine which strategy is appropriate for achieving durable resistance in different types of host-parasite interactions.

The programme is focussed on this co-evolution of plant and parasite at the level of crops and natural populations of the parasite , and on variouson time scales. ranging from annual seasons to geological time (?). It covers various types and qualitative and quantitative expressions of resistance in the host (host, non-host, mono-, oligo- or polygenic *etc*) and variation in the parasite. Fundamental studies on basic genetics, biochemistry and physiology of resistance and theoretical studies pursued in other programmes are being utilised to inform these studies. For example recent theoretical studies indicate that monogenic or specific resistance, which is not normally durable, reduces parasite fitness/aggressiveness, whilst polygenic resistance, often more durable, selects for increased fitness/aggressiveness. A sustainable strategy should therefore achieve an effective balance between these types of resistance and take into account environmental factors affecting their expression.

The longer a resistance can operate effectively against the challenge of the parasite, the more 'durable' it is. Some genes can be very effective, *e.g.* R-genes to late blight in potato, but they are not at all durable, hence potato growers have not abandoned fungicides in their favour. Durability cannot be determined because, by definition, it involves possible events in the future, but it might be possible to make useful predictions about it if there were enough knowledge about the genetics of crop and parasites, parasite migration and the stability of resistance in varying environments.

Work in the programme ranges from basic to applied but is largely strategic. Longer term. its aim is quite practical, namely to set particular and general ground rules for determining the potential benefits of various resistances and strategies for deploying them, for example to determine the relative value of resistances from several wild sources for future exploitation. A variety of plant-parasite systems are covered in the programme (see Table 1), although the same fundamental aim unites all of them, and no type of resistance is excluded from consideration. Thus pesticide resistance in the parasite and genetically modified resistance in the host are not excludedincluded.

Plant	Main areas of study
Potato	
Viruses	Variation within, and resistance to, Tobacco rattle virus (TRV).
Peach aphid	Population dynamics/genetics and movement of M. persicae between potato and other crops.
Late blight	Population genetics and epidemiology of P. infestans pathogen and durability of host resistance.
Trichodorid nematodes	Variation within species and transmission of TRV.
Potato cyst nematode	Population structure and virulence of G. pallida.
Barley	Population structure of Rhynchosporium secalis (leaf blotch) of barley in response to selection. Effect of host heterogeneity on pathogen population structure.
Raspberry	
Viruses	Characterisation, detection, epidemiology and aetiology of virus diseases and resistance to them.
Raspberry aphid	Durability of resistance genes to Amphorophora idaei and transmission of raspberry viruses.
Phytophthora spp.	Aetiology and control of, and resistance to, Raspberry root rot.
Ribes	
Viruses	Characterisation, detection, epidemiology and sources of resistance to Blackcurrant reversion and Gooseberry veinbanding viruses.
Ribes mites	Inter- and intraspecific variation in Cecidophyopsis species and their roles as pests and/or virus vectors.

Table 1 Main interactions studied in the Host-Parasite Co-Evolution Programme.

The scope and nature of the Programmes also implies a considerable amount of work on the aetiology and epidemiology of diseases and pests and of the ecology of the agro-ecosystem in which they are deployed. Much of the epidemiology and associated topics such as diagnostics are not core-funded but funded by contract with private bodies and other government agencies. This mix will be continued in future hopefully with even more participation of non-governmental bodies.

New opportunities and new funding The three other Programmes in Theme 3 – *Ecosystem management and Biotechnology*, the *Plant-Soil Interface* and *Computational Biology* – operate similarly across Themes and to a wide range of external collaborators and agencies. The Theme as a whole still has its base in the arable system but is extending its principles and techniques to a wide range of habitats including those in secondary succession and grassland and peri-urban environments. Within the Theme itself, new research will create synergies to tackle previously intractable problems. Major new laboratory and field experiments, operating across the Programmes, were put in place in 2002 to quantify self-organisation in systems resulting from perturbation and change in crop genotype. A range of major new externally-funded projects also began in 2002. SCRI will lead a multi-institute collaboration on geneflow between crop fields (funded by DEFRA until 2006), is part of a European grouping examining the impacts of GM varieties on soil processes and organisms (EU funded) and leads internationally through new competitive funding for research and for collaborative networks on Phytophthoras. This new funding will allow SCRI to make major advances in genetic diagnostic techniques, spatial processes, mechanisms of pollen and gene movement and more generally heighten our capability to predict the consequences of change in environment and genotype. The grant-in aid from SEERAD provides a strong base and continuity while the present external, competitive grant income of more than £7M is a testament to the Theme's success and relevance to science and the modern world. SCRI is now a major and expanding European centre for research in environmental plant and microbial biology.

References

[1] World Summit on Sustainable Development, Johannesburg, South Africa, 26 August to 4 September 2002. http//:www.johannesburgsummit.org/html/documents/summit_docs/2009_keyoutcomes_commitments

[2] Lewis Grassic Gibbon. 1933. *Clay*. Republished 1993 as Booklet Number 1, The Grassic Gibbon Centre, Arbuthnot Community Enterprises.