Management of genes and organisms in the environment

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

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

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

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

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

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