Plants, soils and environment

Geoff Squire, Karl Ritz & Donald Mackerron

Not far into Naturalists Voyage Round the World[1]*, the traveller asked at a house whether robbers were about, and got the enigmatic reply 'the thistles are not up yet'. To appreciate this reply, the reader is told about the simple three-way interaction between thistles, travellers and robbers. The thistles grew very large at a certain time of the year, and in great beds, affording hiding places for robbers to attack the travellers. The nature of the vegetation determined the safety or otherwise of the people. The modern reader might indeed be fanciful. Would not the locals want to remove the thistles, or at least prevent them growing in such dense thickets? They would need to know how far to diminish them so they no longer provided sufficient space to hide robbers. They could sow a competitive species in among the thistles, or encourage a pest to spoil them, or sow a field nearby with a sexually compatible dwarfing form; or despatch them by an ingenious chemical. In time, by a variety of means, the thistles would have retracted and disappeared. But would not the people begin to miss them, to recall that the beds looked quite attractive in a great mass on a clear evening, catching the low sun, and to realise their roots prevented the soil being washed away in the wet season. Even robbers had become more sophisticated and no longer needed thistle beds to hide in. Some of the people wanted the thistles back, at least as a presence. Fanciful, yes, but these not-quite-so-simple matters of tripartite interactions are what the Division is attempting to understand, if not in every detail, then in enough to be able to suggest how people might coexist better among soil, bugs and vegetation.*

Loss of diversity – loss of function?

Among the more newsworthy aspects of plant biology in 2001 was the matter of halting and reversing the loss of biodiversity from agricultural habitats. Farmland that supports a wide range of plant and animal species is the concerted aim of government advisory bodies such as Scottish Natural Heritage and English Nature, popular organisations such as the RSPB and the Scottish Wildlife Trust, and a great range of more local interests, as well as many farmers and scientists. The loss of weeds is becoming a test case of the effect of humans on their environment, and a focal point for ethics and art – witness a recent commission for the 2001 season of the BBC Promenade Concerts[2]. A high level of biodiversity in arable fields and their margins will become a necessary output of farming. Safeguarding arable diversity will be a prerequisite for the development of high value products from crop biotechnology, including GM varieties. Getting profitable arable farming and biodiversity is not straightforward however. A definition is needed of a suitable level of biodiversity, and then a means found to achieve it. The Division's science is contributing to both of these aims.

On a practical scale, research groups are working to define criteria for the diversity and health of an ecosystem. The tests of soil resilience, described in the previous Annual Report and published in the journal *Oikos,* were later profiled as an 'editor's choice' in *Science*[4]. Our studies into soil biophysics (one of the research profiles following this introduction) and the molecular profiling of soil microorganisms will also contribute to a suite of methods for assessing the state of soil. Research on the arable seedbank has defined simple community-scale features that enable a comparison to be made of UK seedbanks at various times since 1915. Modelling of plant communities will now seek to define the crop genotypes and agronomy that will move seedbanks towards the desired states. The seedbank and the weed vegetation are themselves important sources of food and habitat for insects and mites. Some detailed studies of ecological interactions at these higher orders of complexity are given later in the second of the research profiles.

Our innovative theoretical approach, which defines biodiversity as a distribution of individuals across physiological 'trait space', gained further acceptance through publication in the journal *Nature*[3]. Further progress was achieved during the year through measuring and modelling the life history trajectories of plants. In order to relate vegetation to insects and higher organisms, the two-dimensional distributions of arable plants have to be translated to three-dimensional root and canopy structures. The modelling of this transition needs an appreciation of the way groups of individuals 'self-organise' and thereby distribute carbon and nitrogen among the plates and platforms of the plant canopy.

Geneflow and ecological safety

Research on geneflow and persistence of genes and plants in the environment continued with new funding from SEERAD. The unambiguous pollen sources of the GM Farm Scale Evaluations in Scotland are allowing us to refine estimates of gene movement

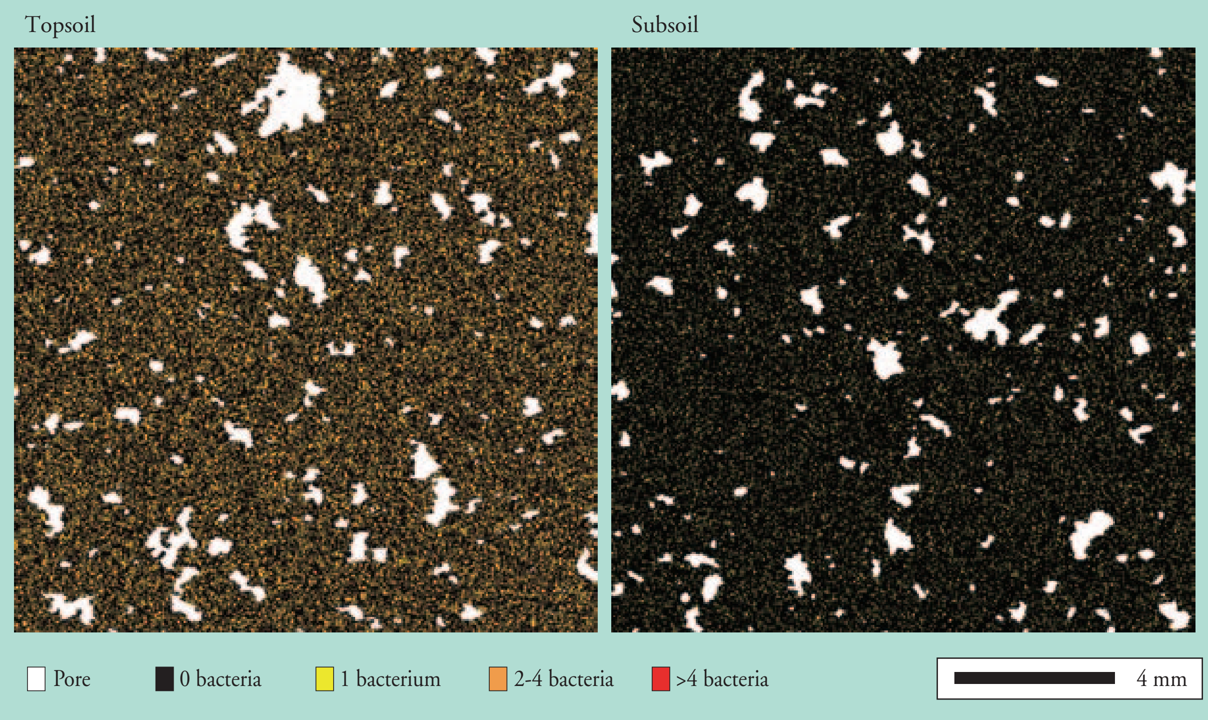

Figure 1 Simulation of bacterial distribution and associated pore networks in mineral soils using Monte-Carlo method Markov-chain model, based on measurement of indigenous cells in an arable soil. The basic mapping unit (i.e. pixel size) here is 20 µm.

from such crops and to define the roles of different insects. (This work is joint with the Unit of Applied Genetics). Staff from SCRI have been asked to give evidence on and to shape policy in this complex area, both in the UK[5] and for the European Commission[6]. These are instances of impartial scientific investigation being translated into sound advice to members of Scottish, UK and European parliaments. The examination of farmland biodiversity in the Farm Scale Evaluations of GM crops has proceeded to schedule. Around 20 visits for data collection were made to each of the farm sites this year. The first results will be available near the end of 2002.

The measurement and role of heterogeneity

To understand such ecological processes needs knowledge of how spatial and temporal heterogeneity in the physico-chemical environment affects the biota. The Division is now able to study heterogeneity over scales from soil pores to regions. For instance, using a combination of high-resolution multiple-scale mapping and innovative modelling, the first-ever detailed simulation maps of bacterial distribution at scales up to 5 cm in soil have been attained (Fig. 1). At scales of several millimetres, bacteria appear to be everywhere, but at smaller scales the cells are heterogeneously distributed and relatively large regions of soil are devoid of microbes. This distribution is important to a wide range of processes in soils, including those by which soil bacteria make certain toxic substances harmless. Flows of solutes through soil are very non-uniform, often following tortuous paths, which once established may persist. Transformation of the toxic material will only occur when compounds are in contact with microbes capable of mediating them, but the main pathways of flow might miss many of the microbes. Typically, only 1-10% of the microbial community can degrade toxins, i.e. most of the cells mapped in Figure 1 will be unable to degrade them. Mathematical models of bacterial locations, solute flows and degradation potential are being extended to three-dimensional space, and should indicate how soil and soil organisms might be managed in a way that brings the solute closer to the bacteria.

Another example is the process of nitrification (conversion of ammonium to nitrate), which is a very important part of the nitrogen cycle in arable soils. Nitrate is highly mobile and can therefore be delivered to plant roots with the mass flow of water, but can also be easily leached from the rooting profile into groundwater. Nitrous oxide is also produced during this process, leading to further N losses from soils, generating a potent greenhouse gas. Previous studies over many growing seasons at SCRI have shown temporal variation in potential nitrification rate (PNR) in arable soils. A new project aimed at detailed mapping of PNR in a study field has shown extensive spatial variation in the process at any one time (Fig. 2), and a unique data set that will enable modelling of the major soil N-cycling processes through the agricultural year. Further work is underway to understand the cause of this variation through molecular analyses of the bacterial communities (e.g. the eubacterial and ammonia-oxidiser bacteria) that are responsible for nitrogen transformations.

Resilience on a still larger scale

Manipulating genotype and resource *together* remains the principal means by which we can continue to feed off the earth's resources without destroying them. The

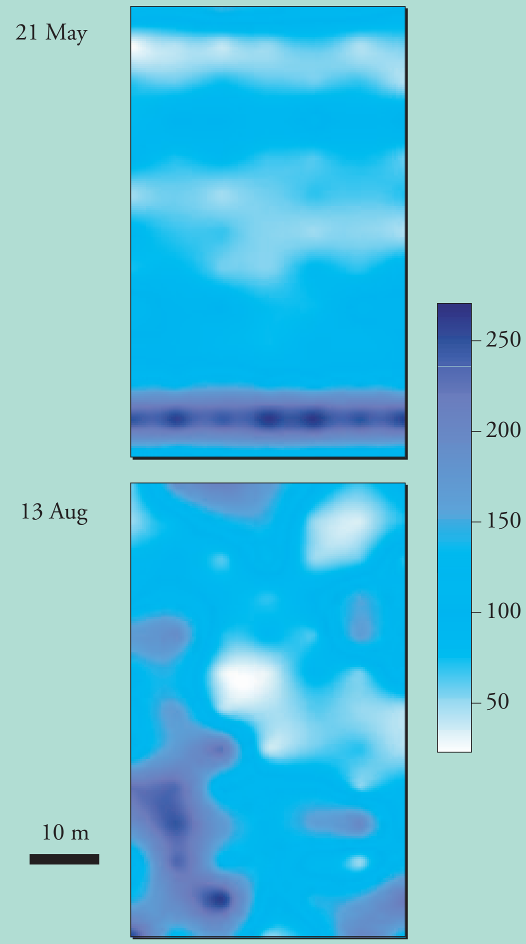

Figure 2 Maps showing spatio-temporal variation in potential nitrification rate (PNR) in soils under spring barley in Bullionfield 2001. Scale shows PNR as µg NO_2-N/g/h.

enormous growth in actual and potential agricultural production over the past 200 years has encouraged the development of society whenever good agricultural principles have been applied. Conway[7], in his influential book on world-wide agriculture, has stressed that being able to continue producing food will require application of the soundest ecological principles with the latest biotechnology. The model ecological system suggested by Conway – the tropical, tiered 'garden' – has justifiably been criticised[8], but the general message remains true. Science, together with the wider interests of society, needs first to define the kinds of arable ecosystems that will satisfy the different ends of cropping, wildlife and greatly reduced pollution. Given this, crop genotypes and agronomy can be devised to meet those ends. Research should be proactive – designing safe and resilient production systems – rather than just reacting to assess the safety of the latest innovation.

The Division has as much to contribute to these global matters of food and environmental security as to the more esoteric arts of fine soil structure and population dynamics. Central to our role is defining and quantifying both the ecosystems and the crop genotypes that fit within them. Research in the Division has therefore seen further movement into barley as the central plant and barley-based arable rotation as the main system of study. This aligns us better with much of the genetical research at SCRI and with the arable systems in the nearby regions and in many other parts of the globe. Research has begun on genetic differences in root architecture and root function in barley, a programme with the potential to link gene expression in roots to rhizodeposition, microbial community function and soil biophysical properties. The ultimate prize is to understand how loss of root material to the soil through root skeletons, sloughing off of root cells, excretion of mucilage and exudation of a variety of chemicals, many at signal strength and of little use as food for soil microorganisms, might regulate the complex behaviour of soil microorganisms and hence the integrity of soil structure. Above ground, research teams have continued to investigate the three-dimensional features of barley canopies, as they affect pathogenesis and the coexisting arthropods. The potential for this science is a predictive understanding of how small changes in genetic information in crop varieties or wild populations propagate through phenotypes to determine features at and ultimately beyond the patch and field.

Finally, we give continued thanks to SEERAD, DEFRA, the research councils and other funders for our growing and diversifying research portfolio, and to those farmers and members of the public with whom we have interacted.

References

[1] Darwin, C. (1890). *Naturalists Voyage Round the World*. New Edition, John Murray, London.

[2] *Knotgrass Elegy* by Sally Beamish. BBC Promenade Concerts. Sunday 29 July 2001.

[3] Pachepsky, E., Crawford, J.W., Bown, J.L. & Squire, G.R. (2001). *Nature* **410**, 923-926.

[4] Editor's Choice (2000). *Science* **290**, 233-234. The original paper is: Griffiths, B.S. *et al.* (2000) *Oikos* **90**, 279-294.

[5] The Scottish Parliament. Transport and Environment Committee Report into Genetically Modified Organisms. 2001. Scottish Parliamentary Corporate Body.

[6] European Commission. Opinion of the Scientific Committee on Plants concerning the adventitious presence of GM seeds in conventional seeds. 13 March 2001. http://europa.eu.int/comm/food/fs/sc/scp/out93_gmo_en.pdf

[7] Conway, G. (1997). *The Doubly Green Revolution*. Penguin, London.

[8] Wood, D. (1998). *Food Policy* **5**, 371-381.