



Agriculture and Environment
Biotechnology Commission

What shapes the research agenda? in agricultural biotechnology

**A report by the Agriculture and Environment
Biotechnology Commission (AEBC)**

Soil science case study

April 2005

Introduction and Context

1. The consultation and information gathering modules of the Agriculture and Environment Biotechnology Commission's (AEBC's) workstream on *What Shapes the Research Agenda?*¹ have identified a number of key drivers of agricultural biotechnology research and thrown up a number of issues around the processes through which research agendas are determined. This case study aims to focus on one area of research in order to identify the important influences on that field of research, and explore the implication of these drivers for the research agenda in that area.
2. Soil science was an area of research highlighted for such a case study early on in the Commission's thinking, because of an often-cited perception that agricultural soil science has declined in recent years. As a more process-oriented and less product- and industry-focused area of science, it contrasts helpfully with our other case study, on plant breeding.
3. This paper has been developed through consultation and discussion with a number of soil scientists (listed in Annex 1), and farming organisations. All those consulted were asked to comment on both an early and a late draft of this paper and largely agreed with its portrayal of soil science. We also sought to represent individual views, although we have not attributed these. However, the content of this paper as a whole is the sole responsibility of the AEBC.

Summary

4. The soil is a highly complex and dynamic system. Understanding its physical and chemical properties is hard enough, but it also harbours a remarkable biodiversity. The relationships between these abiotic and biotic components and the soil's many functions are still poorly understood. Nevertheless, since its beginnings in the 19th century, soil science has helped to produce the vastly improved yields of modern agriculture.
5. The soil's role in a host of other processes, such as carbon cycling and climate change, pollution and ecosystem function, means that factors other than a desire to improve agricultural productivity can influence research agendas. In the last twenty-five years in most Western cultures, the key drivers behind soil science have changed considerably as technical advances have begun to allow fundamental soil processes to be understood. Food production continues to be the driving force behind soil science research in developing countries.
6. Soil science is an interesting case study of how a particular area of science is adapting to changing priorities and as technical developments allow new approaches to be taken. In this case study, we have examined the implications of the redirection of priorities and resources on the soil science that is carried out

¹ AEBC (2005) *What shapes the research agenda in agricultural biotechnology?* URN: 05/1078. For electronic copies of this final report and the five modules that contributed to it, go to www.aebc.gov.uk and click on "Reports". Hard copies are available by calling the DTI publications Orderline on 0845 015 0010 and quoting the Unique Reference Number (URN) code for the paper wanted.

today, including the key areas of work and sources of funding, looking particularly at the consequences for agricultural soil science. We conclude that, after a period of neglect in the 1980s, soil science has entered a dynamic and exciting phase, and a time of great potential to contribute to an understanding of today's most important environmental issues. Of particular relevance to the AEBC's wider research agendas workstream, we also find that the research agenda setting process has proved to be agile in responding to new challenges and opportunities.

7. The reconstruction of soil science to address wider, environmental questions has inevitably meant a decline in the resources directed to agricultural research, and we find that soil science has not yet been able to respond as thoroughly to the sustainable agriculture agenda as it has the potential to do. Some important agricultural questions are in danger of being neglected. We also conclude that the rapid redirection of resources has had a negative consequence on the skills base, with a dangerous loss of expertise particularly in the physical soil sciences. This poses a threat to the multidisciplinary that is necessary for soil science to thrive, and to which current funding structures pose some barriers.

The Nineteenth Century

8. The early stages of soil science from the beginning to the late 19th century developed along two separate lines – the agricultural soil chemistry path and the weathered rock, soil physics and agrogeology path². There was little significant interaction between them until the beginning of the 20th century. However, there were a number of important developments over this period: Liebig's mineral theory of plant nutrients of the 1840s; the recognition of the importance of the soil profile (later known as the pedon) by Darwin and Dokuchaev; the identification of soil forming processes (e.g. the role of earthworms in soil mixing, Darwin 1881); the variable nature of humus (soil organic matter) and its role in soil forming processes (e.g. Mueller, 1840-1926);
9. Consequent upon and following the establishment of the long-term field experiments by Lawes and Gilbert in the 1840s the research at Rothamsted focused on the relationship between soil conditions and fertility and its effect on crop yield. Out of these experiments and many others the first edition of *Soil Conditions and Plant Growth* by Sir E John Russell was published in 1912. His son, Walter Russell, published the eighth edition in 1973, and the eleventh multi-authored edition was published in 1988. The several editions of this book have played no small part in shaping the evolution of soil science in Britain and in many other countries of the world³ recognising that soil science and soil management is a multi-disciplined activity embracing pedology (the study of soil origins and the soil profile), soil chemistry, soil physics, soil biology, plant nutrition and other branches of the life sciences.

2 This paragraph is based on the first chapter of Yaalon D.H., Berkowicz S. (eds.) (1997) *History of Soil Science : International Perspectives*, Advances in Geocology 29, Catena, Verlag, Reiskirchen, Germany.

3 Greenland D.J. (1997) *Inaugural Russell Memorial Lecture – Soil Conditions and Plant Growth*, Soil Use and Management 13, 169-177

10. The **principal drivers of research during the 19th century** were curiosity and a need to understand how to use soils and fertilise them to maintain and increase crop yields. The design of the long-term Rothamsted experiments reflects this: a comparison of the yield of crops grown on soils receiving farmyard manure alone, farmyard manure plus inorganic nitrogen, inorganic nitrogen alone, and various combinations of compound fertiliser materials. The funding came from trusts and farmers committed to improving their husbandry techniques and the output from their farms. Farmers were involved in the research.

The Twentieth Century

11. At the beginning of the 20th century an understanding of the role of microbes in the decomposition of plant residues in returning nutrients to the soil (e.g. Waksman, 1888-1973) was developed, and towards the middle of the century following Jenny's model (1941) of soil nutrient dynamics, different types of model were developed to understand the medium and long-term dynamics of soil organic matter. The early part of the 20th century saw also the beginnings of soil survey in Britain which led ultimately to the production and completion of the 1:250,000 scale soil surveys of England and Wales and of Scotland in the 1980s⁴.
12. **During the first half of the 20th century** a greater understanding of soil chemistry and plant nutrition provided the impetus both to establish the extent of variation in agricultural soils through soil survey and to gain greater understanding of how to manage their nutrient status to support a variety of crops. This was a period during which the Agricultural Research Council was established (1934) and the Agricultural Departments began to take initiatives during and after World War II to improve output from UK agriculture. Thus the funding for soil science during this period was predominantly from the public purse. **The opportunities for the rapid development of soil science and the need to increase crop yields were primary drivers during this period.**

From 1975

13. **These drivers continued to influence developments into the third quarter of the 20th century.** In parallel with the other sciences supporting agriculture there was a rapid growth in funding for soil science and in technological development to produce the bulk of our 'food from our own resources'. This was the case not only in the UK but also in the USA. Commenting on this period, Warkentin (1992), states "*Crop production was the engine driving this effort, and its emphasis was on inputs rather than on managing systems.During this period there was little emphasis on reasoning from processes, it was considered better to measure effect even if it were over short time periods.*"
14. Excellent *empirical* solutions to problems came out of this effort. For example, answers to how much nitrogen fertiliser should be added for maximum crop production were sought and given. There was, therefore, little information developed on the underlying processes or on phenomena that had time scales of more than one or two years. This seems to have delayed an interest in and

⁴ Hollis, J.M. and Avery, B.W. (1997) *History of Soil Survey and Development of the Soil Series Concept in the UK*, Advances in Geology 29

understanding of the biological processes in soils⁵. Much of the research of this period was classified as being applied and descriptive. Nevertheless, through the application of more sophisticated soil analysis techniques and the use of soil survey data to produce land capability and suitability maps, soil technology and the results of 'fertiliser dose-response' experiments provided the basis for increasing crop yields significantly during this period.

15. Then, following first the Rothschild Report in 1971, which embodied the customer-contractor principle but which was critical of the Agricultural Research Council (ARC) and second, the report of the Advisory Committee for Applied Research and Development in 1975, which emphasised the relevance of public research to manufacturing and industry, funding for agricultural research was reduced. Consequently Agricultural Departments and the ARC began a process of prioritisation and a reduction in the numbers of scientists involved in agricultural research.
16. By the early to mid 1980s this process had gathered pace: furthermore the increased output from agriculture and the oversupply of agricultural commodities within Europe brought into question the continued public investment in agricultural research. This was considered also in relation to the need for public research investment to support other industries and the need to improve their competitiveness. The lack of private and commercial investment in agricultural research also began to influence funding policy. Moreover, in 1984 ARC became AFRC, the Agricultural and Food Research Council, with responsibility to include research to address concerns about food safety. Funding for agricultural research continued to be redeployed.
17. The negative impact on *agricultural* soil science research funding in the UK over this period was considerable. During the process of prioritisation several factors appear to have influenced the reduction in resources allocated to soil science. The large increases in crop yields that had been achieved were the result of many improvements in technology – crop breeding, methods of disease and weed control, and not least the information that related crop yield to fertiliser inputs for different soil types and cultivation regimes. With regard to the latter, soil science was deemed to have delivered. In addition, Government policy development indicated that it wished to remove funding from 'near-market' research such as this, which it did eventually in 1990.
18. Priorities were also determined by judgments about the potential for innovation within different areas of science supporting agriculture and the growth of agribusinesses. Developments in cell and molecular biology, and plant genomics were judged to show real promise: with its responsibility to fund science that had the potential to underpin future commercial developments the AFRC moved greater resources into this area of biotechnology. By the mid 80s agricultural soil science seems to have reached a plateau in terms of development and lost some of its innovative zeal. Its period of empirical research appears to have been judged at this time to have been too applied and too 'near market': therefore, in the 'cut and thrust' of prioritisation soil science 'lost out'.

⁵ Warkentin, B.P. (1992) *Soil Science for Environmental Quality – How do we know what we know?* J. Environ. Qual. 21, 163-166

1990 onwards

19. A combination of several changes in research policy direction and an unfavourable view of the current innovative status of soil science at the time led to a greatly reduced capacity for *agricultural* soil science in the UK by the beginning of the 1990s. While the principal driver for soil science up to the mid 80s had been to improve crop yields, this was no longer a priority in terms of Government research funding for the rest of the century. In terms of attracting funding, agricultural soil science had lost its appeal.
20. However, a core capability was sustained and soil scientists were already contributing to approaches that moved the emphasis towards process based research and mathematical modelling. Modelling provided the impetus to gain a much clearer and quantitative understanding of nutrient cycling, particularly nitrogen and carbon, and was used to understand how pesticides moved through the soil. It also led to an interest in processes at the scale of the rhizosphere. Developments in microbiology have begun to allow researchers to identify the role of populations of microbes in nutrient cycling and to use specific organisms to characterise the resilience of soils to pollutant damage and as toxic indicators in water. At the same time, the increased functionality of soil information held in databases and within Geographic Information Systems (GIS) has led to their use in a wide range of environmental and ecological applications, including the assessment of nitrate leaching and nitrous oxide emissions from agricultural soils and the ecological potential of soils for habitats of nature conservation value. Some of these applications have had direct relevance to policy, for example in the water industry. GIS and database technology has helped raise awareness of the multi-functional role of soil in the environment through these and other applications directly related to end users other than primary producers in the agricultural sector.
21. The early 90s was a period of refocus for soil science in the UK. Pollution issues first came to the fore in the 1980s and it became apparent that the issues of public concern were the impact of acid rain and fertilisers on water quality and the ecology of rivers, the resilience of soils to the impact of waste, heavy metals and persistent organic pollutants. There was a decisive shift towards a broader interest in the role of soils in the environment and ecosystem function. As a corollary soil research for agriculture became concerned with the more efficient use of fertilisers and effective use of farmyard manures, and there was a small amount of research to support the development of organic farming. **These were the issues that became the primary drivers during much of the 90s for the limited amount of soil research that was funded.**

Drivers for the Twenty-First Century?

22. The significant shift away from the agricultural production focus of the past, towards environmental protection, is driven largely by Government policy needs, with European Union (EU) policy on soils having a strong influence on national policy. The European Commission (EC) has concluded that the maintenance of the soil resource is central to environmental ecosystem sustainability; it must be

managed, conserved and protected. The EC intends to develop a soil strategy as one of seven 'thematic strategies' foreseen under the EU's Sixth Environment Action Programme. As a first step in the development of an encompassing EU policy to protect soils against erosion and pollution it published a communication, *Towards a Thematic Strategy for Soil Protection*, in April 2002⁶. This communication proposed a soil monitoring directive and the establishment of criteria of soil quality to harmonise data collection and monitoring in EU Member States. Research in some countries of Europe including the UK has been stimulated in anticipation of having to implement these proposals. Other European policies that influence the direction of soil science include the Water Framework Directive, the Nitrates Directive, the Urban Waste Water Treatment Directive and the Landfill Directive – not being soil-specific, these require a more holistic approach to soils as part of the wider environment.

23. Partly as a result of the EU attention, the Department for Environment, Food and Rural Affairs (Defra) has recently published a *Soil Action Plan for England 2004-06*, to improve the protection and management of soils within a range of land uses⁷. There are several research related actions, including a commitment “to review the Defra soil research programme ... to ensure that resources are focused on the most urgent questions”. The Scottish Executive Environment and Rural Affairs Department’s (SEERAD’s) new research strategy for environment, biology and agriculture research includes “protecting the nation’s soils” as one of its twelve programme objectives⁸.
24. At the international level an important impetus developed in the late 1990s prior to and following the Kyoto Protocol to the UN Framework Convention on Climate Change, which was signed in December 1997. The Protocol contains legally binding commitments to limit or reduce greenhouse gas emissions within the period 2008-2012 by at least 5% below 1990 levels. Europe’s commitment is to achieve an 8% reduction and the UK has committed itself to a 12% cut with a voluntary target of 20% below that of 1990. Associated changes in the net fluxes of two other greenhouse gases identified in the Protocol – nitrous oxide and methane – will have also to be taken into account. The problem of how to quantify the soil sources and sinks, to maximise carbon sequestration, and to minimise soil emissions of methane and nitrous oxide presents a major scientific challenge to the soil science community over the next few years⁹.
25. At the same time as the aims of soil science have moved towards environmental objectives, there has been a shift towards soil biology at the expense of soil physics, chemistry and pedology. Many argue that biology lies at the heart of the scientific enterprise of the twenty-first century in general, and see soil science as an integral part of that enterprise. Technological developments in biology have changed soil science and created new potential for progress. Much of the focus, and investment, lies today with the use of modern molecular biological and microbiological techniques. Polymerase chain reaction- (PCR-) based techniques

6 See <http://europa.eu.int/comm/environment/soil/#1>.

7 See <http://www.defra.gov.uk/environment/land/soil/actionplan.htm>.

8 SEERAD (2005) *Strategic Research for SEERAD 2005-2010: environment, biology and agriculture*

9 Smith, K.A. (1999) *After the Kyoto Protocol: Can soil scientists make a useful contribution?* Soil Use and Management 15, 71-75

and latterly genomics and other 'omic' sciences have allowed identification, quantification and functional characterisation of soil microorganisms in ways that were not achievable before using traditional cell culture methods.

26. Important practical issues require soil biology knowledge. These include understanding the role of soil processes and soil organic matter in global warming and strategies to ameliorate it; enhanced and safe recycling of waste from manures, urban and industrial activity; pollutant destruction at waste disposal sites as well as landscapes contaminated from natural processes; biological control of rhizosphere pests; enhanced groundwater quality; discovery of new biotechnological products, including pharmaceuticals, pesticides and enzymes from the undiscovered microbial diversity of soil; and optimising recycling of soil nutrients for sustainable agriculture and forestry¹⁰. The basic premise behind an attempt to understand the complex soil community is that further knowledge will pay off in improvements in agriculture, environmental decision-making and management, and many of the practical issues listed above.

Soil science today

27. How have the major changes to soil science described above affected the type of research actually done? Our discussions with a number of soil scientists (as listed in Annex 1) provided us with a series of illustrative snapshots, which we have used to make a number of observations. It is not intended to be an exhaustive survey of current soil science; this has already been done in the October 2003 UK Soil Research Audit¹¹ (see also below).
28. Notwithstanding the growing importance of molecular biology, soil chemistry and soil physics are still practised, though it is within these disciplines that the shift to the big, global environmental questions such as climate change has been greatest. Several of the organisations we spoke to included little soil molecular biology work in their research portfolios, including Reading, Rothamsted and IGER (North Wyke).
29. Descriptions of the work carried out in the organisations we looked at confirmed that agricultural questions were only a small element of soil science today. However, **there is work of direct relevance to agriculture**. Much of this is of a basic or strategic nature, and is focused on natural and fundamental processes, and environmental rather than production issues¹². Nevertheless, advances in applying knowledge and understanding of nutrient cycling (particularly nitrogen) have led to nutrient (fertiliser) management models that are of practical significance. Other agriculture- and environment-related topics include:
- research aimed at understanding rhizosphere systems, root-soil-microbial interactions, and root mechanics;

10 Tiedje, J.M. et al (2001) *Soil Teeming with Life: New Frontiers for Soil Science* in Rees R.M., Ball B.C., Campbell C.D. and Watson C.A. (eds) *Sustainable Management of Soil Organic Matter*.

11 See <http://www.defra.gov.uk/environment/land/soil/research/researchaudit.htm>.

12 Although one area that is more applied is the production of information technology-based decision-support tools for farmers and land managers.

- manures, composts and other organic materials, the chemical and microbial processes occurring in them, nutrient uptake from them and their effect on soil;
 - soil microbiology and microbial ecology/biodiversity, including microbial pathogens and the identification of bio-control agents for them and protection of soil microbial functions for sustainable use;
 - nutrient and water supply, and movement of organic and inorganic compounds through soil into water.
30. Another significant area of work involves looking at **biogeochemical cycling** of carbon and nutrients through soils. This is of great relevance to climate change and also, for example in the case of nitrous oxides, to pollution. Carbon and nutrient cycling can be examined at a number of scales, from local to global, and frequently involves mathematical modelling. On the landscape scale, there is also a body of work focusing on **soil aspects of land management**, and interactions with water quality and pollution. This links to policy in these areas by providing a scientific underpinning and methodologies to determine environmental risk from human activities.
31. **Bioremediation** is another major focus for soil science, again driven by EU and national regulations on decontamination of polluted soils. A number of biological, chemical and physical methods, and both high- and low-tech approaches, are being looked at to remove contaminants from soil. Examples include:
- molecular characterisation of soil organisms and managing the soil environment to create the right conditions to best allow existing microorganisms to clean the soil;
 - hydrocarbon-based bioremediation;
 - nanotechnology – the use of photocatalysis to remove contaminants.

Sources of funding

32. The main funders of soil science continue to be the research councils – primarily the Biotechnology and Biological Sciences Research Council (BBSRC) and the Natural Environment Research Council (NERC) – and Government departments – primarily Defra and SEERAD. The Engineering and Physical Sciences Research Council (EPSRC) funds a certain amount of engineering- and material science-related soil science. Government department funding appears to be concentrated somewhat in particular institutes (rather than University departments): Rothamsted and IGER for Defra and SCRI, MLURI and the Scottish Agricultural College (SAC) for SEERAD. The balance between Research Council and Government department funding varies considerably as key policy needs change. In the late 1990s, for example, around three quarters of soil science research at Rothamsted was funded by Defra, as part of their nitrates research programme, but today this has declined to about one quarter, with some of the slack taken up by BBSRC funding.
33. Wealth creation is a key driver behind all publicly funded research. However, it appears to be relatively unimportant for soil science compared to other areas. There is no ‘soil science industry’ like the agricultural biotechnology or agrochemical industries, and therefore industry funding of soil science research is relatively low. Fertiliser and other agrochemical companies fund some research,

as do the agricultural levy bodies, but few of the scientists we spoke to receive significant funding from these sources. Some industry-funded research is driven by EU and policy requirements, notably the Existing Substances Directive and the Registration, Evaluation and Authorisation of Chemicals (REACH) legislation. These often put the onus on industry to provide the basic scientific information for the assessment of environmental risk and risk mitigation strategies. **So, the main source of industry funding among those we consulted was in the area of bioremediation**, and unrelated to agriculture. Although driven by policy requirements to clean up land, bioremediation is very business-oriented because companies that own contaminated land bear responsibility for remediating it, and contamination affects the availability of land for building and other commercial purposes. Both CEH Oxford and Aberdeen University are involved in the *First Faraday* partnership between industry and academia, which is targeted at developing technologies for the assessment, remediation and management of contaminated land, and transferring these to generate new, technologically derived business¹³. At Rothamsted, the main source of industrial funding is from companies involved in mining and mineral extraction.

34. Other significant sources of funding include:

- European Union programmes.
- Other Government Departments, including the Ministry of Defence in relation to contaminated land. Department for International Development (DFID) funding was significant until recently, but appears to have declined heavily in recent years because of an increasing change in focus towards the social sciences.
- Charities such as Leverhulme Trust.

Implications of current soil science agendas

35. Government and international policy appears to be the most significant driver behind soil research agendas, with wealth creation less prominent than in other areas of research. But these are only two of the four key drivers that the AEBC has identified in its analysis¹⁴. What influence do the other two have?

- Public aspirations for science in society
- Advancing knowledge and technology and maintaining the science base

36. Public and stakeholder concerns related to soil science are addressed indirectly through policy needs, which tackle areas of concern such as pollution, climate change and biodiversity. Our analysis has not revealed any direct sources of input from the general public into soil research agendas. This is not surprising, and there is no reason to propose that public input into the detail of a soil science programme of research is required. However, at a strategic level it could be argued that the public should have an opportunity to influence and protect soil science as a discipline that is fundamental to our understanding of the natural world. Mechanisms do exist for stakeholder (mainly farming and commercial stakeholder) involvement in setting research agendas, such as their inclusion on the Boards of Governors of research institutes and through their input into general

13 See <http://www.firstfaraday.com>. Faraday partnerships are a Department of Trade and Industry initiative to promote improved interaction between the UK science, engineering and technology base and industry.

14 AEBC (2005) *What Shapes the Research Agenda? Information and Analysis Paper*, URN 05/1082

policy making on soil (e.g. Defra's Soil Action Plan Advisory Forum). But several of the soil scientists we spoke to felt that the involvement of the wider stakeholder community is limited and that **stakeholder influence on research agendas is minimal compared to that of Government policy needs and the Research Councils.**

37. The desire to advance knowledge, and scientific curiosity still drive soil science to an extent, particularly in University departments. A Soil Science Advisory Committee, made up of scientists from Universities, Research Institutes, Industry and Funding Bodies was set up in 1995 by BBSRC and NERC, to represent the interests of the soil science community and provide a link between soils research and the main funding bodies¹⁵. In research institutes, however, several soil scientists told us that the need to attract Government Department funding, and the consequent strong focus on research to meet policy needs, had **reduced the freedom of staff to pursue curiosity-driven research.**
38. New technology is certainly a key driver, as discussed above. Indeed, some of those we spoke to felt that the great potential offered by biotechnology (in the broad sense) had not yet been properly exploited and that work had sometimes been overly focused on technological development rather than applications. **The drive to discover more about the hidden microbial diversity in soil comes largely from disciplines outside of agricultural and environmental science,** and regards waters and soil primarily as gene banks¹⁶ that may yield biotechnological and medical solutions as well as extend our knowledge of life strategies and evolutionary processes.
39. A specific interest of this case study was whether farmers' concerns are addressed by soil science today, and whether the redirection of resources away from agricultural questions has had any negative consequences. There are a number of knowledge transfer programmes in place to relay findings to farmers. However, there is a perception that farmers' concerns are addressed less directly than previously, and food surpluses and the decline in the economic importance of agriculture have reduced their impact. Farmers are still largely focused on yield and quality (although CAP reform is changing this), and therefore the change in the direction of soil science away from these areas has reduced its relevance to them¹⁷.
40. **There are important and ongoing agricultural soil science questions that still need to be addressed, and some of the people we spoke to said that there was a funding gap in this area.** With 70% of land in the UK still farmed, farming is important not just for the agriculture industry but also for land management in general. There is also a need to approach problems in an international context and look to the needs of the developing world, if sustainability is to be genuinely addressed. In addition to the areas mentioned in paragraphs 20 and 26 above, several areas of agricultural soil science where more research is needed were pointed out to us:

15 See <http://www.nerc.ac.uk/funding/tfwsci/ssac.shtml>.

16 See <http://www.sorcerer2expedition.org/version1/HTML/main.htm>

17 Note the similarity here to our other case study, on plant breeding, where we found that market demand for new crop varieties was still dominated by increasing yield and quality.

- improved understanding of soil fertility and nutrient uptake by plants;
 - soil management strategies for agriculture, particularly for low input and precision production methods;
 - organic fertilisers and recycling of crop residues and other organic materials;
 - questions raised by changing patterns of land-use by farmers e.g. “hobby” farmers in peri-urban areas in the UK;
 - maintaining funding for crucial long-term experiments.
41. One scientist said that the gaps identified in research agendas have not yet had major consequences because the current generation of soil scientists has a background and training in agricultural issues and still identifies with agricultural uses of land. However, he asked whether future generations would continue to do so. This brings us to what was universally agreed by all those we spoke to as the biggest problem facing soil science today: **the threat to the soil science base in the UK and the potential for irreversible loss of expertise.**
42. Crudely speaking, soil science comprises three separate disciplines: soil chemistry, soil physics, and soil biology. In the past, these have sometimes been too isolated from each other, but good soil science requires an understanding of all three, and a collaborative, multidisciplinary approach. The emphasis on biology, and modern biological techniques, means that younger scientists tend to focus exclusively on molecular biological methods, and important gaps in knowledge are appearing in other areas. Soil science degree-level courses are increasingly rare, and soil science PhD positions hard to fill. As a result, many of the soil scientists who will retire in the next 10 to 15 years are likely to be difficult to replace. Soil physics seems to be particularly at risk, but soil chemistry is also threatened and soil classification and mapping were also mentioned. **Despite the strength in soil biology, its outputs may be constrained by a lack of skilled physicists and chemists, resulting in an inability to extrapolate results to the reality of the soil environment and its landscape context.**
43. In response to these problems, and in order to stabilise and strengthen soil science in a diminishing funding environment, BBSRC has established a Cross Institute Programme in Sustainable Soil Function, at IGER and Rothamsted. There is an aim to increase the collaboration to cover other, non-BBSRC institutes, including CEH and MLURI, in the future¹⁸.
44. Some of those we spoke to also said that **research funding structures can hinder the cross-disciplinary nature of soil science and the integrated, multidisciplinary approach required.** While BBSRC and NERC have good links between them, they are not felt to be receptive to multidisciplinary proposals. They were said to have particular difficulty in dealing with research proposals that tried to take a holistic, systems based approach. In addition, some pointed to coordination problems between basic, molecular level science (Research Council funded) and applied, environmental impact work (Government Department funded) and the lack of a middle ground between the two areas.

18 IGER (2004) *Annual report and accounts 2004: director's introduction*

Conclusions

45. A UK Soil Research Audit, commissioned by Defra and SNIFFER (Scotland and Northern Ireland Forum for Environmental Research), was published in October 2003¹⁹. The audit concluded that there had been a decline in fundamental soil science research, particularly in pedology, soil mineralogy and surface chemistry. This decline had adversely affected training opportunities for the next generation of soil scientists. However, future soil science needed to be multidisciplinary and international in scope²⁰, and should aim to become a key component of wider environmental science issues. It concluded that now was a time of great opportunity and challenge for soil research because an increasing knowledge base allowed it to contribute to tackling some of the major environmental issues, including climate change, pollution and sustainable land management. Our analysis and the discussions we have had with a range of soil scientists reinforce many of these conclusions.
46. We chose soil science as a case study topic because of a perception that we had picked up from some stakeholders that it was in decline. This is clearly not the case. In fact the research agenda setting process has been shown to be agile in responding to new challenges and opportunities. The policy drivers behind soil science have diversified hugely in recent years. We believe that the expansion in the ambit of soil science over the last twenty years from agricultural questions, particularly agricultural production, to environmental issues of global importance, is necessary and welcome. Coupled with the new avenues opened up by technological advances, particularly in soil biology, this **makes soil science a dynamic, responsive and exciting area.**
47. With finite resources, no research area can be optimally funded, and it is inevitable that the greater diversity of the soil science agenda will lead to a reduced coverage of areas that have benefited traditionally. Therefore, while soil science has successfully been reconstructed to address a new set of environmental questions, gaps exist on the agricultural research side. We do not intend to make recommendations on the relative priorities of agricultural and other areas of soil science. However, we note that soil science appears only to be in the early stages of responding to the sustainable agriculture agenda and that **there are some important agricultural soil science questions that are in danger of being neglected.**
48. The redirection of resources in soil science has had an important and unintended negative consequence for the skills base. **The rapid pace of change in soil science has meant that not enough care has been taken to protect the full range of soil science skills and expertise.** This problem needs to be addressed in soil science and avoided in the future. It is closely related to another issue illustrated by our case study: the **difficulty of successfully fostering the**

19 See <http://www.defra.gov.uk/environment/land/soil/research/researchaudit.htm>.

20 Some of the scientists we consulted felt that an international scope was crucial because of mounting environmental pressures and threats to sustainability (e.g. deforestation to create new agricultural areas in South America, rapid economic development [agriculture and industry] in Asia and a need for agricultural development in Africa).

multidisciplinary approach that everyone agrees is required for soil science, within current research funding structures.

49. **Research agendas must be flexible and quick to adapt in the face of changing requirements and new opportunities. However, change must always proceed with one eye on protecting the existing skills base to avoid irreversible and damaging loss of expertise, and ensuring that important existing areas of research are not neglected.**

Annex 1: Soil scientists consulted for this case study

Organisation	Individuals consulted	Main soil research Interests
Agriculture and the Environment Division, Rothamsted Research	Professor Keith Goulding	<ul style="list-style-type: none"> • Biogeochemical cycling • Bioremediation and soil protection • Soil physics and mathematical modelling
Department of Soil Science, University of Reading	Professors Peter Gregory and Stephen Nortcliff	<ul style="list-style-type: none"> • Remediation and containment • Carbon and energy fluxes • Sewage sludge and compost • Phosphorus in farm to water system • Rhizosphere, from soil and plant point of view
Environmental Sciences Group, Macaulay Land Use Research Institute (MLURI)	Dr Colin Campbell and Mr Willie Towers	<ul style="list-style-type: none"> • Soil-plant microbial interactions • Catchment management
Microbial Diversity Group, Centre for Ecology and Hydrology (CEH) Oxford	Professor Ian Thompson	<ul style="list-style-type: none"> • Bioremediation (First Faraday partnership) • Microbial degradation of land-fill gases, industrial wastes and pesticides
School of Biological Sciences, University of Aberdeen	Professor Ken Killham	<ul style="list-style-type: none"> • Bioremediation (First Faraday partnership) • Soil-plant microbial interactions • Carbon-nutrient cycling • Microbial ecology of Icelandic soils
Soil, Environmental and Ecological Sciences Department, Institute of Grassland and Environmental Research (IGER) North Wyke	Professor Steve Jarvis	<ul style="list-style-type: none"> • Basic soil mechanisms in grazing systems • Manures and farm resources • Soil biodiversity
Soils Programme, Scottish Crop Research Institute (SCRI)	Professor Blair McKenzie	<ul style="list-style-type: none"> • Soil biology using molecular and non-molecular techniques • Soil engineering, root mechanics • Sustainable agroecosystems and the resilience of soil to stress from modern farming systems
Nafferton Ecological Farming Group, School of Agriculture, Food and Rural Development, University of Newcastle	Professor Carlo Leifert	<ul style="list-style-type: none"> • Organic agricultural systems development • Soil fertility management • Biological control of pests and diseases • Composting technology

All those listed above were sent a first draft of this case study, to which they responded in writing, through a face-to-face meeting or by telephone. They also provided information on the soil science conducted in their organisation. They were then given the opportunity to comment again, on the final draft.

