A number of parameters and processes remain uncertain and will need further investigations for their quantification. The most important of these include:

- fluxes in the soil;
- a quantification of resource availability for the vegetation cover.

3 Networks and consortia

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3.1 Introduction

The successful implementation of GCTE's (Global Change and Terrestrial Ecosystems) large and complex programme can only be accomplished by involving many members of the global research community and by bringing together the enormous amount of pertinent national, regional and international research. This chapter describes how GCTE is achieving this integration by using networking as a fundamental research strategy, and how the networks and consortia are established and managed. Much of the science achieved in this way is reported elsewhere in this volume, but examples are given that are relevant to the various types of network now established.

3.2 Advancing science by networking

Research programmes in terrestrial ecosystems science are increasingly dependent on national, regional or global collaboration. A common mechanism adopted by many groups to achieve this collaboration has been the use of networks, i.e. groups of researchers linked or brought together to exchange ideas and to undertake joint research. If well designed, this allows two major benefits to be derived: First, networks allow for research that could not be accomplished independently (e.g. experiments where many individual sites or studies are required, enabling the generation of results greater than the sum of the parts. Second, 'added value' of a financial nature can be achieved, as a result of sharing data, models and facilities, all three of which can be expensive to obtain, develop, and build and maintain.

Experience with many networks has identified a number of requirements for success:

- The network's goals must be clearly stated and scientifically exciting in order to engage good scientists.
- The individuals in the network must benefit in addition to the group as a

whole; the initial enthusiasm and momentum of the network will only be maintained if the individual researchers continue to benefit from their active participation.

- It must be clear what benefits (both for the individual and the network) will be gained, and also what the responsibilities are (see Box 3.1); a wide spectrum of network approaches means that interpretation of the concept may vary.
- Success and momentum are maximized when there is a sense of 'ownership' of the network by the members. This can be achieved by jointly designing the network, and by maximizing participation in synthesis workshops, publications, etc. Although the network may be centrally administered, it cannot have 'top down' management. Rather, the network members need to decide collectively what should next be addressed.

Box 3.1 Benefits and responsibilities of participation in GCTE Core Research

To achieve its objectives, GCTE is developing a coordinated research programme built around 45 Tasks, each addressing specific scientific questions within GCTE's broad objectives. Each Task consists of a limited number of complementary research projects coordinated by a Task Leader(s), which collectively meet the Task's objectives. Within each Task a variety of mechanisms, such as common experimental protocols, standardized methodologies, model comparisons, and integrating workshops and symposia, are used to knit the contributing projects together into a coordinated effort.

Although GCTE aims for the highest scientific quality in its portfolio of contributing projects, it does not carry out full peer review evaluations. That process is undertaken in the normal way by the grant-giving body that funds the project. GCTE works with many of these granting agencies to ensure that the highest standards of scientific quality are maintained in projects accepted in the GCTE Core Research Programme, and to maximize the complementarity of the agency's scientific objectives with those of GCTE and other IGBP Core Projects.

Participation in the GCTE Core Research Programme has a number of significant benefits for component projects. The Programme:

- facilitates the planning of research projects addressing aspects of global change and terrestrial ecosystems by providing a soundly based intellectual and organizational framework for research, with overall aims, approach and implementation developed and endorsed by the international science community;
- adds to the scientific value of individual experimental, observational and modelling studies and assists in their interpretation by organizing networks and consortia which widen the range of observational studies and extend their temporal and spatial coverage, promote common methodologies and protocols, and provide datasets for model validation and intercomparison;
- promotes the rapid communication of scientific ideas and results through meetings and publications, and by facilitating disciplinary and interdisciplinary liaison at the international level between individuals and research groups;
- provides assistance to contributing projects in obtaining funds from national and international sources by writing letters of support and lobbying, where appropriate;
- assists in the cost-effective deployment of major capital equipment and facilitates such as FACE by providing the scientific framework for their phased deployment and assisting in their collaborative use;
- encourages the full involvement of developing countries through GCTE participation in the START regional research networks;
- promotes close working links with other relevant international programmes and studies, particularly those of other IGBP Core Projects and Framework Activities, and of IHDP, WCRP and other international research organizations;
- promotes the concepts of GCTE and IGBP science, and the results obtained from the GCTE Core Research Programme, to ensure their wider recognition among the international research and policy communities.

Participation in the GCTE Core Research Programme requires a commitment to:

- participate in the relevant GCTE Task(s) for which the project was accepted through activities such as implementation and synthesis workshops, model intercomparisons, and joint observational studies;
- carry out the project in accordance with the relevant aspects of the GCTE Operational Plan using agreed methods and protocols wherever possible;
- make data and models available to the wider GCTE community, in accordance with protocols for data and model exchange developed by GCTE networks and consortia, and with due regard to publication 'rights';
- keep the GCTE Core Project Office informed on an annual basis of (i) major changes to the project objectives, description, and participating research organization and changes in the annual budget and the major funding agencies; and (ii) changes to the number of scientific and technical staff working on the project, and provide the Core Project Office a list of publications arising from the project;
- acknowledge participation in the GCTE Core Research Programme in publications arising from the project by inserting in the Acknowledgements the sentence 'This work contributes to the Global Change and Terrestrial Ecosystems (GCTE) Core Project of the International Geosphere–Biosphere Programme (IGBP)'.

The establishment and running of successful collaborative research networks requires two essential inputs: a commitment on the part of the network members to help keep the network 'alive' through active involvement; and sufficient resources (in both funds and skilled time) to administer the network's establishment and operation.

3.3 GCTE networks

GCTE is *itself* a network, established by IGBP (International Geosphere – Biosphere Programme), with clearly defined (if broad) goals. The design and refinement of the GCTE agenda (Steffen *et al.*, 1992) through a series of international planning workshops was wholly dependent on discussions among a very large number of scientists from around the world, a process which resulted in GCTE's internationally agreed-upon research agenda. GCTE keeps this group informed of developments and progress by publishing a newsletter (now mailed to over 1800 recipients worldwide), and has established a home page on the worldwide web (http://jasper/stanford.edu/GCTE/). The number of scientists becoming actively involved in GCTE research is rising sharply, often as a result of participation in one of the networks described below.

There are three specific scientific reasons why the network approach is particularly valuable for GCTE: First, much of the GCTE research agenda addresses global-scale issues (e.g. increasing CO_2 and mean global temperature), or more site-specific issues which are so widely manifest as to be considered a global phenomenon (e.g. soil erosion); in both cases a wide geographic spread is central to the research, especially when responses across a range of temperature and precipitation are needed to represent anticipated climate change. Second, many of the research themes, by their very nature, require a multi-disciplinary approach. Third, since GCTE aims to develop quantitative tools, it is essential that experimentalists and 'tool developers' (e.g. modellers) are brought together, preferably also with potential users (e.g. the policy and resource management communities).

GCTE networks (Table 3.1) vary considerably in their objectives and degree of formality. Some aim to compare and synthesize information. Others, in addition, have more infrastructure for cataloguing and collaboratively designing research, and require members to use agreed, standard experimental protocols and data formats, or exchange data and model code. Those of the first type have been termed 'consortia' rather than networks, but this mainly reflects history rather than differences in operation.

Working within the general area identified by the early planning workshops, inaugural network meetings refine the individual components and determine the specific objectives for given networks. Common experimental protocols (if appropriate) are agreed upon and a time-scale for network activities established. A network Steering or Working Group is usually appointed, comprising specialists from a range of relevant disciplines, and networks are typically launched with a small number of contributing projects and then grow as more groups worldwide become involved.

Networks initiated by Focus 3 ('Global Change Impact on Agriculture, Forestry and Soils') often start with the collation of existing experimental datasets and models, and the collation of 'metadata' (data describing a piece of research, as distinct from the data or model code itself). This initiation serves more than just the establishment of network membership; it helps determine what GCTE-type studies are ongoing, where coordinating effort should be placed, and where new projects should be initiated. Questionnaires soliciting metadata are widely distributed, together with an invitation to apply to join the network. All applications are reviewed by an international expert panel (Network Working Group), and the conditions of acceptance are twofold: the quality of science and the pertinence to network objectives. Experiments contributing to the network must have sufficiently detailed measurements to enable the models to be evaluated and developed, and models must be mechanistic in design. The evolution of a typical GCTE network, that for Soil Erosion, is described in Box 3.2.

GCTE research networks fall into three categories: (i) networks of sites, where the research depends wholly or substantially on a geographical spread of experiments; (ii) thematic networks, where work is linked according to the topic being researched; and (iii) regional networks of researchers undertaking studies of the impacts of global change on terrestrial ecosystems. There are, however, cases where studies fall under more than one category.

3.3.1 Site networks

The GCTE Soil Organic Matter Network (SOMNET, part of Focus 3) includes a worldwide set of long-term soil organic matter management experiments. The datasets from these are an essential resource for the development of the soil organic matter (SOM) turnover models (also included in SOMNET) which aim to simulate SOM dynamics over decades to centuries. Many suitable experiments have been identified so far (mostly in the US, Europe and Australia) and other sites – particularly in the tropics – are being sought. To be included in SOMNET, the experiments, some of which are over one hundred years old, must provide datasets suitable for model evaluation.

Another network, about to be launched, is the Long-term Agroecological Experiments Network. Experiments will be included where two or more species have been grown together for at least 10 years. Data from these will be used to evaluate the role of planned diversity in sustainable production. Several of these long-term agroecological experiments may also prove valuable for SOM studies and links between the two networks will be promoted.

The role of networks of sites is further discussed in Chapter 4.

Table 3.1 *GCTE networks and consortia*

Title	Objective(s)	No. of Members	No. of Countries	No. of Models	No. of Dataset
Site Networks					
SOMNET	To use data from long-term experiments to evaluate and develop Soil Organic Matter (SOM) turnover models	40	16	22	34
Thematic networks					
Elevated CO_2 Consortium	To foster, coordinate and integrate research on ecosystem response to increasing atmospheric [CO_2], with main emphasis on whole-ecosystem experiments in which other environmental factors, biotic interactions and long-term feedbacks are accounted for	27	15	n/a	n/a
DGVM consortium	To develop and improve Dynamic Global Vegetation Models (DGVMs) by performing intercomparisons using standardized input data	5	4	4	1
Wheat Network	To refine and adapt current wheat production models for use in global change studies in a wide variety of conditions; and to design and undertake experiments to provide improved mechanistic understanding of global change impact on wheat production, to aid in model development	39	17	20	53
Rice Network	To develop, improve and evaluate models of the rice crop and agroecosystem; to conduct experiments to test scientific hypotheses and to provide data that contribute to the development and evaluation of rice crop models; and to foster improved experimental protocols that support both scientific hypotheses and crop modelling needs	12	8	7	8
Potato Network	To refine and adapt current potato production models for use in global change studies in a wide variety of conditions; and to design and undertake experiments to provide improved mechanistic understanding of global change impact on potato production, to aid in model development	10	6	5	11
Pastures and Rangelands Network (CRP1)	To predict the effects of global change on pasture and livestock production at the paddock scale	16	10	6	15
Experimental Forest Network	To design and undertake experiments, where long-term feedbacks are accounted for, to provide improved mechanistic understanding of global change impact on structure and function of managed forests; and to use results from such experiments to develop, improve and evaluate models for use in global change studies in a wide range of managed forests	8	7	4	n/a
Soil Erosion Network	To refine and adapt current soil erosion models for use in global change studies in a wide variety of conditions; and to design and undertake experiments to provide improved mechanistic understanding of the relationships between global change and soil erosion, to aid model development	24	10	9	16
Impacts Networks					
Impacts Centre, Southeast Asia	To build the capacity of Southeast Asian scientists to undertake global change studies; to conduct policy-driven studies; and to provide an advisory network with the policy community	n/a	7	n/a	n/a
Information Networks					
Pastures and Rangelands	To disseminate GCTE findings more broadly to the scientific community and to advise appropriate end users during the course of the research activities	312	48	n/a	n/a

Box 3.2 Key stages in the development of the *GCTE Soil Erosion Network* (part of GCTE Task 3.3.2 'Soil Degradation')

Date	Event	Outcomes/Product	Ongoing activities commenced
Jan 1991	GCTE Open Meeting (Brighton, UK): GCTE general planning	Draft GCTE Operational Plan	
Sept 1991	Focus 3 Open Workshop (Lunteren, NL): Focus 3 general planning/scoping exercise	Draft Focus 3 Operational Plan	
Mar 1993	Internal planning meeting (Oxford, UK)	Task 3.3.2 (Soil Degradation) Inaugural Workshop designed	Inaugural Workshop planning
Mar 1994	Inaugural Workshop (Paris, France)	Task's major objectives agreed; major erosion models and monitoring projects identified; metadatabase structure developed; Task Working Group convened	Metadatabase structures developed for models, manipulative experiments and monitoring programmes; invitation to join network widely distributed; follow-up workshop preparation
	Publication of Paris Workshop Report (GCTE Working Document 11, Ingram, 1994)		
Feb 1995	Network Planning Workshop (Corvallis, US). Task Working Group meeting	Model sensitivity analysis planned for water erosion at plot scale. 4 Core Research Projects (CRPs) planned; criteria for network membership established; inaugural membership agreed; Special Issue of *J. Soil & Water Conservation* designed	Preparation of inaugural members' metadata for submission to GCTE Scientific Steering Committee for ratification as GCTE Core Research; plot scale model sensitivity analysis workshop planning; JSWC Sp. Issue editing
Apr 1995	GCTE Scientific Steering Committee meeting (Bariloche, Argentina)	Soil Erosion Network (GCTE-SEN) formally recognised as GCTE 'Core Research'	
Sept 1995	Network Workshop: 'Global Change: Modelling Soil Erosion by Water' (with NATO; Oxford, UK). Task Working Group meeting	Results of model sensitivity analysis reported and outlines of NATO ASI book chapters produced. Model sensitivity analysis planned for water erosion at catchment scale	Editing NATO ASI book chapters; catchment scale model sensitivity analysis workshop preparation
Sep 1995	Publication of revised Focus 3 Operational Plan including revisions to Task		
Jan 1996	Network Workshop: 'SALT' Experimentation Planning (Senegal, Burkina Faso & Niger). Task Working Group meeting	Field collaboration planned along SALT transect (see Chapter 4)	
Apr 1996	Publication of Soils Activity (Activity 3.3) Implementation Plan (GCTE Report 12)		Editing metadata. Distribution of A3.3 Implementation Plan to current and prospective members of GCTE-SEN; selected projects invited to contribute to GCTE-SEN; detailed planning for Utrecht workshop
Oct 1996	Publication of 5 papers as Sp. Issue of *Journal of Soil and Water Conservation*, 51		Collaborative work on water erosion at field-scale started in Senegal

Box 3.2 *(cont.)*

Date	Event	Outcomes/Product	Ongoing activities commenced
Dec 1996	Publication of metadata for models, experiments and modelling programmes (GCTE Report 6)		
Early 1997	Publication of Oxford NATO workshop book in NATO-ASI Series		
Apr 1997	Network Workshop: 'Modelling water erosion at catchment scale' (Utrecht, NL)	Series of papers for publication in book or journal special issue anticipated	Editing Utrecht papers Detailed planning of GCTE presentations at Wind Erosion Congress, GCTE-LUCC Open Science Conference, Activity 3.3 Session at ISSS Congress, and Focus 3 Science Conference
Nov 1997	Network Workshop: 'Erosion Thresholds' (Almeria, Spain)	Erosion thresholds Core Research Project (CPR2) launched. Detailed plans for GCTE Erosion Network input to GCTE-LUCC Open Science Conference and GCTE Special Session at ISSS Congress; and proposals for input to Focus 3 Conference	
Mar 1998	GCTE-LUCC Open Science Conference (Barcelona, Spain)		Focus 3 session to include reporting of Soils Activity results
Aug 1998 planned	ISSS Congress: GCTE Activity 3.3 Session (Montpellier, France)	Series of papers as Journal Special Issue	Editing ISSS Special Session papers
Sept 1999 planned	Focus 3 Science Conference (Reading, UK)	To include a full review and synthesis of GCTE soil erosion research	Editing Focus 3 Conference papers

3.3.2 Thematic networks

GCTE has launched several thematic networks and consortia where the emphasis is on linking similar types of research or research addressing a similar issue. Geographical spread, although common, is not always a primary objective.

The 'Elevated CO_2 Consortium' (Fig. 3.1), launched by Focus 1 'Ecosystem Physiology' in 1992, has gained considerable momentum, and a consortium of developers of dynamic global vegetation models (DGVM) has been established by Focus 2 'Ecosystem Structure and Function'. The work of these two consortia is further described in Chapters 7 and 8, respectively.

Many of GCTE's thematic networks have model comparison as a central activity. Many of the models involved in these exercises have previously been well evaluated for the conditions for which they were developed. To use them with confidence for global change studies, however, they need to be tested for robustness under conditions outside the environmental 'envelope' in which they were designed. This analysis requires a thorough and systematic evaluation using data from contrasting experimental sites. Several GCTE networks, especially those in Focus 3, are designed to deal specifically, or in part, with this issue.

GCTE is implementing much of its research on agriculture through a series of Crop Networks. Networks for wheat, rice and potato are now well established (see Table 3.1), and are formally recognized as GCTE Core Research. Similar networks for cassava, sorghum, maize and groundnut are being planned.

The Crop Networks have linked objectives:

- To refine and adapt current crop production models for use in global change studies in a wide variety of conditions.
- To design and undertake experiments to provide improved mechanistic understanding of global change impact on crop production, to aid in model development.

An initial goal is the identification of models, or modules, for application to field experimental programmes. A major aim is then to determine (by model comparisons with contrasting datasets) the robustness of well-established and new models under conditions of environmental change, and to provide a guide to the application of crop models under global change within national programmes. Model evaluation is an important step in this process, but it is not intended to be a competition. Rather, it is designed to stimulate the further development of generic crop models for global change studies by identifying strengths and weaknesses in existing models (see Chapter 9 for a discussion of results from the GCTE Wheat and Rice Networks). A further aim is to strengthen model links to 'yield reducing' factors (see Box 9.1, Chapter 9); the Crop Networks will further integrate pest, disease, weed and soil components with the current simulation models for major crops, to allow better predictive capabilities for whole agricultural systems for changed environments.

Models have often been developed using experimental data from closed and open top chamber experiments, but will eventually be tested against datasets generated by the Free-Air CO_2 Enrichment (FACE) (and other field-scale) experiments (see Chapter 2). In addition to global change experiments, which provide ideal datasets for the analysis of model responses to, for example, elevated CO_2, many experiments with no formal global change dimension are valuable for analysing the effects of contrasting photoperiod, soils or irrigation.

GCTE's managed forest programme, also part of Focus 3, has launched a research network combining elements of both the 'site' and 'thematic' approaches. Unique within GCTE, this network has implemented detailed common experimental protocols for investigating interactions of elevated CO_2 and nutrients. This will greatly facilitate the synthesis of results across the network, while quantifying the specific environmental factors contributing to site results. Initial network sites are in boreal and temperate systems.

3.3.3 Regional networks for impact studies

There is a strong and growing need for the developing world to strengthen links both within major regions (between scientists and with the policy community), and between regional scientists and global change scientists worldwide. In response to this a series of regional networks is being developed dealing specifically with impacts of global change. These are established in close collaboration with the START (Global Change SysTem for Analysis, Research and Training) programme, and are termed Impacts Centres. The philosophy of these Centres is to conduct policy-driven studies and to provide an advisory network to the policy community. A regional approach helps identify problems common to neighbouring countries, therefore allowing for the more efficient sharing of resources and application of results.

GCTE Impacts Centres aim to assist regional scientists build their own capacity to analyse, interpret and predict the impacts of global change on terrestrial systems, including agriculture, production forests, natural ecosystems and nature reserves; and to promote planning for sustainable development and biodiversity conservation. These aims will be achieved by offering training courses, research fellowships, study visits and small equipment grants; by undertaking collaborative impact analyses with appropriate groups in the region; and by providing expert advice to the policy community and resource managers. The Impacts Centres will also facilitate regional involvement in GCTE networks, and in applying strategic research results to regional issues.

The first of the Impacts Centres was launched in 1995 with a grant from the

Australian Government. Located in Bogor, Indonesia, to serve Southeast Asia, it is designed to be self-supporting in the long-term by obtaining grants and contracts through regional partnerships. Other Centres are planned for South America, Southern Africa and South Asia.

3.3.4 Information networks

To complement the research networks described above, a fourth type of network has also been developed. 'Information networks' link together a wide group of researchers and appropriate end users. They provide a mechanism regularly to distribute information on GCTE findings and activities for application to resource management and for guiding new research directions and efforts; they do not involve a specific research programme. An example is the GCTE Pastures and Rangelands Information Network, which has over 300 members worldwide. These include users in the pastoral industries and scientists currently active in GCTE research. Importantly, it also includes groups or individuals in different regions that may not currently have active global change research programmes, but which are considering developing such programmes based on information obtained through the Information Network.

3.4 Standardizing networking 'tools'

3.4.1 Experimental protocols

Agreeing upon common experimental protocols is notoriously difficult; persuading laboratories to change well-established methods to a new standard, finding methods suitable across widely ranging conditions and different levels of training, equipping and infrastructure are all commonly cited reasons. Nevertheless, progress is often frustrated until common protocols are established. Many of GCTE's Tasks, networks and core research projects (CRPs) are tackling specific standardization issues, usually by convening international working groups.

3.4.2 Collation of metadata

Collations of metadata (metadatabases) are an efficient way of determining and communicating what data and models are available for synthesis, integration and analysis. They also serve well in enabling researchers both to 'advertise' their work, and to identify suitable opportunities for bi- and multi-lateral collaboration, without compromising their intellectual property; having little intrinsic intellectual content, metadata can be made widely – and freely – available.

GCTE has invested considerable effort in developing a series of metadatabases because information presented clearly in a systematic way is quick and efficient to search, and allows a good overview of a given piece of research, whether model or experiment. By asking specific questions, the metadatabase design also shows potential network applicants what types of research are of interest to the network, and a 'worked example' of completed metadata indicates the level of detail requested. GCTE compilations of metadata are published in the GCTE Report Series (Table 3.2) and on the GCTE worldwide web site. They are often unique references for global change research on selected topics.

3.4.3 Data requirements and the advantage of a standard file structure

One of the primary objectives of the GCTE networks is to compare, refine and evaluate simulation models for use as tools in global change studies. This requires that, firstly, models work well and, secondly, suitable data exists to permit their application. To determine how well models work, data are initially needed to evaluate them. An understanding of the quality of the data is crucial, and close cooperation between modellers and experimentalists is required to establish this.

Model evaluation requires a balanced coverage of datasets representing a range of environments. Datasets need to cover all normal and, where possible, extreme growing conditions. Crops datasets, for example, should cover a range of cultivars and management practices (including pest, disease and weed control), and should include data on phenology, yield (and other plant components) and total biomass, leaf area index (LAI) development and disease, pest and weed impact. To obtain quality data, their variability must be recognized (i.e. an adequate number of samples must be taken), as well as their consistency (e.g. whether there are missing values, or varied ways of measuring parameters were used), one of the main problems inherent in datasets.

Model application requires the selection of a range of representative sites and/or regions with known cultivar characteristics and crop management. Data on regional yields and meteorology are required to evaluate regional applications.

GCTE has made rapid progress in developing standardized protocols for the collection and dissemination of data, most notably from agricultural experiments. The gathering of new data of a suitable type can be costly so it is essential to use such comprehensive datasets as widely and efficiently as possible. Additionally, there are existing datasets that are inadequate for model construction but which can provide useful datapoints for validation across multiple environments and conditions. Access to both types is facilitated by adopting a standard format for data collation, and, for crops, an example is well documented by the International Benchmark Sites Network for Agrotechnological Transfer

Table 3.2 *Major products from GCTE networks and consortia: books and journal special and thematic issues*

Ballantine, S. (ed.) (1996). GCTE Soil Erosion Network papers. *Journal of Soil and Water Conservation*, 51(5) (Special Issue; 5 papers.)
Boardman, J. and Favis-Mortlock, D.T. (eds.) (1997). *Modelling Erosion by Water*. Springer-Verlag NATO-ASI Global Change Series, Heidelberg.
Cramer, W. and Woodward, F.I. (eds.) 1996. A Global Key of Plant Functional Types (PFT) for Modelling Ecosystems Responses to Global Change. *Journal of Vegetation Science*, 7(3). (Special Issue; 14 papers.)
Hirose, T. and Walker, B.H. (eds.) (1996). Global Change and Terrestrial Ecosystems in Monsoon Asia. *Vegetatio*, 121(1). (Special Issue; 16 papers.)
Koch, G.W. and Mooney, H.A. (eds.) (1996). *Carbon Dioxide and Terrestrial Ecosystems*. Academic Press, San Diego. 443 pp.
Körner, Ch. and Bazzaz, F. (eds.) 1996. *Community, Population and Evolutionary Responses to Elevated CO_2*. Academic Press, San Diego. 465 pp.
Nösberger, J. and Campbell, B.D. (eds.) (1997). Interactions between elevated CO_2 and water supply in grasslands. *Global Change Biology* 3(3). (COST-GCTE Thematic Set; 7 papers.)
Powlson, D.S., Smith, P. and Smith, J.U. (eds.) (1996). *Evaluation of Soil Organic Matter Models*. Springer-Verlag, Berlin. 429 pp.
Schulze, E.-D. and Mooney, H.A. (eds.) (1993). Design and execution of experiments on CO_2 enrichment. *Ecosystems Research Report* 6, European Commission, Brussels. 420 pp.
Luo, Y. and Mooney, H.A. (1999). *Carbon Dioxide and Environmental Stress* Physiological Ecology Series, Academic Press (*In press*).
Smith, P., Powlson, D.S. Smith, J.U. and Elliott, T. (eds.) (1997). Evaluation and comparison of soil organic matter models using datasets from seven long-term experiments. *Geoderma* XX (Special Issue; 12 papers.)
Smith, T.M. (ed.) (1996). The application of patch models of vegetation dynamics to global change issues. *Climatic Change* 34(2). (Special Issue; 15 papers.)
Smith, T.M. Shugart, H.H. and Woodward, F.I. (eds.) (1997). *Towards the Development of a Functional Classification of Plants*. IGBP Book Series No. 1, Cambridge University Press. 369 pp.
Steffen, W.L., Walker, B.H., Ingram, J.S.I. and Koch, G.W. (eds). (1992). Global change and terrestrial ecosystems: the operational plan. *IGBP Report*, 21. IGBP, Stockholm. 95 pp.
Stott, P. (1995). Global Change Interactions with Terrestrial Ecosystems. *Journal of Biogeography*, 22(2–5) (Special Issue; 88 papers.)
Tinker, P.B., Gregory, P.J., Canadell, J. and Ingram, J.S.I. (eds). (1996). Plant–soil carbon belowground: the effects of elevated CO_2. *Plant and Soil*, 187 (Special Issue; 19 papers.)
Walker, B.H., and Steffen, W.L., (eds). (1996). *Global Change and Terrestrial Ecosystems*. IGBP Book Series No. 2. Cambridge University Press. 619 pp.
Walker, B.H., Steffen, W.L., Canadell, J. and Ingram, J.S.I. (eds). (1999). *The Terrestrial Biosphere and Global Change: Implications for Natural and Managed Ecosystems. A Synthesis of GCTE and Related Research*. IGBP Book Series No. 4. Cambridge University Press. 432 pp.

(IBSNAT) and GCTE (Box 3.3). The International Consortium for Agricultural Systems Applications (ICASA), in collaboration with GCTE, is currently refining these data standards.

Box 3.3 Standard file formats

Standard datafiles should be machine-readable and use only ASCII characters, which are easily understood, transferred and edited. Datasets should be self-contained and include comments on quality, authorship and variable names. A suitable data structure is: *dataset title; !comment; @header with variable names/ abbreviations; and with 'space' used for delimiters.

A worked example is thus:

```
*EXP.DATA(A) : WABO8201 NITROGEN
!EXAMPLE FOR GCTE
@TRNO ADAT CWAM
1 83172 14000
2 83174 14500
3 83180 15000
```

The objective of designing standard files is to simplify the transfer, storage and multiple use of datasets. It is not an attempt to constrain data reporting, but merely to avoid a large number of conversion programmes being required. A few file-naming conventions help to promote universality, but it is important to maintain scope for local names. Standard files need defined codes, but also need scope to add new codes and to define them within the file, which applies both for variable names and for inputs. The structure of input and output data for the models also needs to be standardized for ease of model comparison and interchange of model components, and the IBSNAT input format (Hunt *et al.*, 1994) is proving successful. It has been formally adopted by the Crop Networks, and it may also be of value to other networks.

Network members are encouraged to convert their datasets into the GCTE standard, and GCTE offers advice and some assistance in doing this. The goal is to have all network datasets thus converted to maximize the ease of transferability and model validation. Significant progress has been made for the Wheat Network, with 31 datasets now converted and stored in the standard format.

3.5 Protection of intellectual property rights

The emphasis placed on networking, and hence on sharing and exchanging data and model code, has generated much debate on the protection of intellectual property rights. GCTE has addressed this by drafting its own Data and Model

Box 3.4 GCTE Data and Model Sharing Policy

Many of GCTE's Tasks involve experimental and modelling networks that call for the sharing of data and models among network members. The 'spirit' of GCTE is to share models and data, as far as institutional or other constraints will allow. The following guidelines clarify GCTE's policy regarding ownership and sharing of data and models.

1. Property Rights. All data and models (computer code) remain the property of the research worker(s) who obtained it. No network member or coordination centre shall pass data or models on to a third party outside the network without the owner's expressed permission. The data and models shall not be used in GCTE publications, other than with the permission of the research worker(s) concerned.

2. Use within Network. There is often a long lag time between the collection of data or the evolution of a model or model component to a 'stable' state and its publication in the scientific literature. The GCTE networks aim to reduce this lag by facilitating the exchange of data and models prior to publication. GCTE will ensure that such exchanges preserve the originator's right to legitimate first use of the data and model, their right to know to whom within the network the information has been distributed, and the recognition of priority. Members of GCTE networks are obliged to observe these rights, and to release models and data to other current members of the network and to the coordinating centre under these conditions.

3. Publications. Each researcher is encouraged to publish his/her work in the normal way, and is requested to state in the acknowledgements that the work is a contribution to the GCTE Core Research Programme. Reprints of publications will be gratefully received by the GCTE Core Project Office and the relevant Focus Office.

4. Synthesis and Reviews. One of the aims of GCTE is to conduct syntheses of the data gathered from sites within a network. Once synthesised, data from specific sites will lose their individuality and become part of the GCTE regional, and ultimately global, picture. Those conducting a synthesis exercise on behalf of GCTE may feel that their work merits publication in its own right, and they should be encouraged to publish in an appropriate journal. Any such paper must include suitable acknowledgement of contributing research workers, and state that it is part of the GCTE Core Research Programme. Should published data be used in the synthesis, references must be made in the normal style of a review.

Any contributor whose data are used in a significant way and whose data collection is wholly or largely intended for the network is entitled to become a co-author. It must, however, be recognized that there is a level of participation (or data use) below which addition of a further co-author would be inequitable to major authors. In the unlikely event that concern regarding inclusion or not of a given co-author becomes an issue, the Chairman of GCTE will confer with those concerned and act as arbitrator.

These guidelines are not legally enforceable, but it is expected that members of GCTE networks will abide by them.

Sharing Policy (Box 3.4), in which the key issues are presented. A condition for membership in many of the GCTE networks is that the project's principal investigator signs an undertaking to abide by the terms of the policy.

The agreement by all members of a given network to share data and code, working under the 'protection' of the terms of the policy, has both advanced scientific progress and helped GCTE knit the wide-ranging communities into coherent and effective collaborative partnerships.

3.6 Networking benefits and products

From its inception GCTE has benefited from improved communication technologies and the establishment of scientific collaborative links between researchers worldwide. This is a major factor in GCTE's gathering momentum; over 400 scientists attended the First GCTE Science Conference held in Woods Hole, USA in 1994 (Stott, 1995; Walker & Steffen, 1996). Many new collaborative links have developed (usually between scientists from different countries – and often between different disciplines), and the strong links built between wide-ranging groups of individuals and teams have resulted in effective international partnerships to undertake global change studies.

The individual GCTE networks are also proving very effective, and have gained considerable scientific momentum. Once the research goals were established, formal networks have helped to identify, collate, organize and undertake research. An analysis of a network's contributing projects shows not only where the strengths of the network lie but also where thematic and geographic gaps exist. Networking thus provides a systematic mechanism for reviewing ongoing research and planning the next generation of experiments and model exercises.

Networking also provides a mechanism for including projects which, in themselves, might not form part of GCTE's Core Research Programme (being, for example, too site-specific). For instance, the Elevated CO_2 Consortium has identified and integrated results from many ecosystem-level CO_2 research projects from a worldwide range of natural ecosystems, and several detailed syntheses of the effects of increasing atmospheric CO_2 have now been conducted (Fig. 3.1). Similarly, the rapid progress witnessed in the highly complex issue of DGVM development (see Chapter 8) has been substantially due to GCTE bringing together the world's leading DGVM groups, particularly for model comparison exercises. A third example is the assemblages of worldwide datasets for crop, forage and tree growth, increasingly in standard format, and the rigorous and candid examination and development of models ranging from single-point, single-season crop growth models to global, long-term simulations

Past and Planned GCTE Sponsored and Co-sponsored Workshops in the area of Ecosystem Responses to Elevated CO_2 (1992–1999)

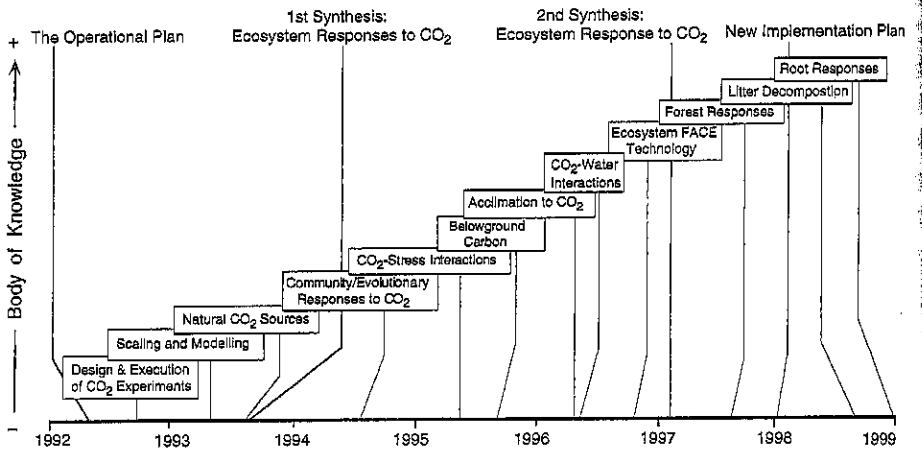

Figure 3.1 Elevated CO_2 consortium 'Time-line'.

of forest stand dynamics; these would not have been possible without GCTE networking.

Networks of relatively small research undertakings can amount to sizeable financial investments, particularly where the collation of long-term datasets are concerned. For example, the estimated 'value' of the field data (i.e. the cost of undertaking all the experimentation) included in GCTE SOMNET has been calculated (Smith *et al.*, 1996*a*). By assuming that each long-term experiment at Rothamsted Experimental Station, UK cost US$12 500 per year to run in 1989 (a conservative estimate), then multiplying this figure by the number of years the experiment has run, an estimate of the 'value' of that experiment's data can be derived. Summing similarly derived figures for all the experiments in SOMNET yields the figure of US$35.6 million (Smith *et al.*, 1996*b*).

GCTE networks have already produced several interim products. Networks' results are often rapidly published and disseminated in the GCTE Working Document Series, or lead to multi-authored papers in the peer-reviewed literature. In addition to these numerous multi-authored papers, several books and journal special issues have been published as a direct result of GCTE network activities (Table 3.2). Network activities have also produced reports and implementation plans which are made widely and freely available in the IGBP and GCTE Report Series, and as GCTE working documents. Finally, networks have also assisted in developing and publicizing proposals for synthesis, experimentation and model development. This has furthered international collaboration and has strengthened interdisciplinary links between ecologists, soil scientists, crop physiologists, pest, disease and weed scientists and agronomists.

The progress reported above and elsewhere in this volume has not, however, been without cost; much discussion and significant amounts of very limited GCTE resources and staff time have gone into network design, membership establishment and arranging and raising funds for model comparison and synthesis workshops. In addition to these costs, networks run the risk of loading an administrative burden upon the members. GCTE has therefore sought to minimize administrative effort on the part of the network membership while maintaining close links among them, and with the working group and the Task Leader(s).

3.7 Conclusions

The benefits and examples of achievements discussed above show how networks have helped GCTE, and highlight why networking is central to many of its implementation strategies. While networking may not always be the best approach to all research issues – and indeed many projects in the GCTE Core Research portfolio are 'stand alone' – it has often proved the *only* way to achieve success. In addition to the results from the individual networks, the effective communication and collaboration established by GCTE (as a network itself) has rapidly advanced the community's breadth and depth in the understanding of terrestrial ecosystem science; it has directly resulted in this synthesis volume.

Finally it is worth noting that, although a primary goal of GCTE is to develop a predictive capability to support long-term planning and adaptation strategies, the existence of well-established networks of experts constitutes a major asset in the event of sudden, unexpected environmental changes. The GCTE networks, and their equivalents in the other IGBP, IHDP and WCRP projects, provide a 'reaction force', capable of diagnosing unanticipated events and developing adaptation responses. This may prove to be one of the most important products of the current international global change research effort.