Series on Science for Sustainable Development No. 7

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Global Environmental Change and Food Provision: A New Role for Science

ICSU Series on Science for Sustainable Development

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Global Environmental Change and Food Provision: A New Role for Science

Prepared by
P. J. Gregory, M. Brklacich, J. S. I. Ingram,
D. Whelpdale and with contributions from
members of the FAO Inter-Departmental
Working Group on Climate Change in
Relation to Agriculture and Food Security

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Preface

The scientific community has been instrumental in reducing uncertainties regarding the functioning of the Earth system. Through concerted international efforts, major scientific advances have been made that document past trends, describe the functioning of planet Earth and provide scenarios for the future.

Four major scientific research programmes provide the underpinning of international political efforts to address global environmental change; DIVERSITAS – an international programme of biodiversity science, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimension's Programme (IHDP) and the World Climate Research Programme (WCRP). Although the four programmes have distinct responsibilities, they have also faced the challenge of working closely together to address common issues. These bold scientific ventures have not only provided the necessary integration among disciplines such as physics, chemistry and biology, but also fostered strong partnership with the social sciences. Such international collaboration between "the two scientific cultures" is unprecedented and supplies the necessary components of scientific research that is policy relevant.

In the current development of the international global change research programmes, it has been decided to focus on three cross-cutting issues: carbon, food and water. These three issues are all crucial in the context of sustainable development. The challenge for these bold new undertakings will also be to develop global environmental change research within a local context. It is the farmer in his fields who through management practices influences the carbon stock in soil and vegetation, and the farmer manages the soil and water resources in the way that optimises the production of biological natural resources. The farmer is at the centre of the complex food production system. Any scientific attempt to address global environmental change and food provisions must also address the scaling issue. The research must be relevant to the local communities and thus involve farmers and other stakeholders in a participatory way, while being nested in the overarching four global change research programmes. This will be a major challenge for the science community. If successful, the results will certainly be highly policy relevant for sustainable development.

The UN Secretary-General Kofi Annan has recently presented an address "Towards a sustainable future" in which he outlines five areas where concrete results are both essential and achievable: water and sanitation; energy; agricultural productivity; biodiversity and ecosystems management; and health. These are all areas where the scientific community has much to offer. This Report gives one example of an important new research initiative addressing the urgent need for adequate food provision taking into account the global environmental changes that will affect the local production systems. A vision for a sustainable future should be based on knowledge societies in which the scientific community has an important role to play. We will accept this challenge and hope to provide the leadership necessary to address major issues such as food provisions where we can make substantial contributions.

Professor THOMAS ROSSWALL

Executive Director
ICSU

Summary

Projected increases in human population together with an improved diet indicate that current production of food will need to be raised substantially over the next few decades. Past increases in production are having major effects on changes in land cover, nitrogen availability and cycling, and biodiversity and, when coupled with other human activities, especially those linked to the burning of fossil fuels, add to the global environmental change (GEC) first highlighted in relation to atmospheric composition, climate variability and climate change.

Production, availability and access to food (components of food provision) are all affected by various elements of GEC so that future food provision is uncertain. The overall human vulnerability to GEC is affected by both biophysical and socioeconomic vulnerabilities. While changes in temperature are likely to be greatest in northern latitudes, future shortages of water and current degradation of soil resources are particularly important in much of Africa, the Middle East and South and East Asia. So, the impact of GEC is likely to be most acutely felt in parts of the world with many of the least developed economies. This, coupled with the high socioeconomic vulnerability of many of the same regions is also likely to limit the ability of societies to adapt in a timely manner to the changes that are anticipated. In particular, the adaptive ability of Africa with its high biophysical vulnerability, its relatively large population living on the edges of areas with an adequate growing season, and its relatively weak political institutions, must be of concern.

Global Environmental Change and Food Systems (GECAFS) is a new policy-relevant research project that aims to determine strategies to cope with the impacts of GEC on food provision and to analyse the environmental and socioeconomic consequences of adaptation. It is being implemented via regional research projects that can identify the effectiveness of alternative policies at different points within food provision systems.

Global Environmental Change and Food Provision: A New Role for Science

Food production and food provision: the underlying issues

Projected increases in human population together with an improved diet indicate that current production of food will need to be raised substantially over the next few decades (Dyson, 1996; Evans, 1998). The world's population has already risen from 2.5 billion in 1950 to its current 6 billion and is projected to be about 8 billion by 2025 (Fischer and Heilig, 1997). Much of this increase will occur in cities of the developing world with urban populations doubling within 20 years. Rising per capita incomes of this urbanised population will result in significant increases in the demand for food crops, meat, fish and forest products (Alexandratos, 1995; Pinstrup-Andersen *et al.,* 1999). Cereal production has increased from 740 Mt in 1950 to about 1,900 Mt in 1995 and will have to increase by another 690 Mt to meet projected demand in 2020 (Dyson, 1996). The increased demand is not only for direct human consumption but also to meet the projected 1.4% p.a. increase in cereal feed for livestock production over the next two decades (Delgrado *et al.,* 1999).

Past increases in agricultural production have occurred as a result of both extensification (altering natural ecosystems to generate food products for human consumption) and intensification (producing more of the desired products per unit area of land already used for agriculture). About 3 billion ha of the world's land is suitable for arable agriculture and 1.2 to 1.5 billion ha of the most productive land is already cultivated (Greenland *et al.,* 1998). Most of the potentially available land is presently under tropical forests. Cultivation of more of this land is undesirable with respect to biodiversity conservation, greenhouse gas emissions and regional climate and hydrological changes. In addition to these unacceptable environmental costs, developing the infrastructure required to support agriculture would be expensive and economically difficult to justify. Future potential to enhance food provision systems will consequently rely more on the intensification of existing production systems rather than further extensification. Typically new areas of land will only contribute 7.4% (51 Mha) to cereal production on a global basis by 2020. Estimated contributions of extensification to crop production range from 47% in sub-Saharan Africa to 18% in South Asia. Intensification will thus be the dominant means for increasing production. This will be achieved largely by increased yields per area rather than increased number of crops grown in a seasonal cycle. For instance, average cereal yield has already increased from 1.15 Mg ha^{-1} in 1951 to 2.8 Mg ha^{-1} in 1995 and is projected to be about 4.2 Mg ha^{-1} in 2020. Simultaneously *per capita* arable land area has declined from 0.235 ha in 1951 to 0.127 ha in 1993 (Dyson, 1996; Greenland *et al.,* 1998). It is this increased production per unit area that is at the heart of many environmental concerns (Gregory *et al.,* 2002).

The need to increase production raises questions about both the sustainability and potential environmental consequences of current and future production systems (Matson *et al.,* 1997). Concerns over the former have been heightened by the realisation that cereal yields are either decreasing or increasing less rapidly than hitherto in many countries. Environmental issues are often confusing and difficult to classify but are concerned generally with damage to the natural capital, particularly soils, water and air. Gregory *et al.* (2002) examined the environmental consequences of three broad types of crop intensification and showed that the consequences differed markedly between types and particularly in whether the major effects were on- or off-site.

Important though the concept of food production is in the debate, of ultimate interest is food *provision.* Food provision is governed by production of food, availability of food, and access to food (see Box 1). When food provision is adequate, the necessary conditions are in place for people to achieve food security. As Box 1 suggests, food provision is concerned with both the environmental factors, which regulate, and

***Box 1:** Food Provision*

Food provision is governed not only by production, but also by the availability of, and access to, food. Access to food is a function of economic potential, physiological potential (e.g. nutritional quality) and food availability (which depends on production and distribution). Food production is a function of yield per unit area and the area from which harvest is taken.

Production	=	f_1 (yield, area)
Availability	=	f_2 (production, distribution)
Access	=	f_3 (availability, economic & physiological potential)
Food Provision	=	f_4 (Production, Availability, Access)

A wide range of sciences are needed to address the components of the "Food Provision Equation": estimates of food production are founded in agroecology, agriculture and fisheries sciences, while issues related to distribution are largely researched by social and policy-related sciences. The broad notion of access requires consideration of a further set of disciplines including economics, sociology and nutritional sciences.

impact on agricultural production and the socio-economic constraints, which ultimately govern, all aspects of food systems.

Over the last 40 years, increases in food supply have outpaced population growth in most regions and, in general, *per capita* food supply has increased. Table 1 indicates that, while the most significant gains have been achieved in Asia, all regions have achieved aggregate supply levels that should be adequate to eliminate hunger. However, food is not equally provided for the world's population either between or within countries (Table 2). Based on data for the period 1996-98, more than 35% of the national population in 24 developing countries (of which 18 are in sub-Saharan Africa) did not have access to enough food to permit them to engage even in light activity without loss of body weight. Further, with more than 45% of the undernourished population in sub-Saharan Africa lacking more than 300 kcal per day, the depth of hunger there was much more severe than in other regions (Figure 1). FAO projects that, if current trends continue, the number of undernourished people in developing countries could decline from around 790 million in 1996-98 to around 575 million in 2015. Again, though, the most significant improvements are foreseen for China and India, whereas no significant change is projected for Africa (FAO, 2000). Many reasons for the poor food provision in Africa have been suggested including weak political leadership, war, inadequate transport infrastructure, reduced rainfall in some regions, and mining of soil nutrients and associated soil degradation.

Global environmental change and food provision

It is now well established that human activities, especially those linked to the burning of fossil fuels, are having a major effect on the global environment (IGBP, 2001; IPCC, 2002). Air and water allow rapid transfer of the effects of some activities around the globe but on land the transport processes are slower so that it is the repeated, cumulative effect of local scale activities that result in the globally important consequence. The term "global environmental change" (GEC) is used to describe the key issues involved. These principally include changes in land cover, atmospheric composition, climate variability and climate, water availability and quality, nitrogen availability and cycling, biodiversity, and sea level.

Widespread changes in production practices have extended the reach of the impacts of agricultural systems on the environment and these impacts are now of global concern. For example, the practice of adding nitrogen fertilisers to crops coupled with the adoption of nitrogen-fixing crops and pastures now means that the quantity of nitrogen fixed anthropogenically exceeds that fixed by natural ecosystems

Table 1. *Per capita energy (kcal per person) supply in different regions of the world in 1961-63 and 1995-97 (from FAO, 2000).*

Region	**1961-1963**	**1995-97**
Africa	2100	2415
Asia	1920	2660
Latin America and Caribbean	2340	2770
All Developing Countries	1960	2627
Countries in Transition	3150	2780
Developed Countries	2970	3220

Table 2. *Prevalence of undernourishment in 1979-81 and 1996-98 (from FAO, 2000).*

	Prevalence of undernourishment in 1979-81 and 1996-98			
	Number (million)	Share of world's food insecure population (percent)	Share of world's total undernourished population in the region (percent)	
	1996-98	1996-98	1979-81	1996-98
Asia	515.2	62	32	17
Latin America and Caribbean	54.9	7	13	11
Near East and North Africa	35.9	4	9	10
Sub-Saharan Africa	185.9	22	38	34
Total Developing Countries	791.9	95	29	18
Countries in Transition	26.4	3	NA	6

(Vitousek, 1994; Vitousek *et al.*, 1997). Biodiversity has frequently declined as a consequence of agricultural intensification and added to the more commonly reported environmental concerns such as greenhouse gas emissions to the atmosphere (Walker *et al.*, 1999).

Agriculture, then, contributes to GEC and elements of GEC will affect agricultural productivity and the provision of food. GEC will bring additional complications to the already difficult task of providing sufficient food of the right quality to many sections of society. Improving food provision in the face of GEC, while at the same time minimizing further environmental change, is a crucial scientific and societal issue.

Vulnerability of food provision

Production, availability and access to food are all affected by various elements of GEC so that future food provision is uncertain. There is a need to both prepare existing food sys-

tems to cope with the immediate impacts of GEC and adapt food systems for changed environmental conditions in the longer term. Not all parts of the world or, indeed, individuals and sections of society are equally vulnerable to GEC and its effects. There is considerable variability in the capacity of individuals and groups to cope with existing variability in biophysical and socioeconomic systems, and in their ability to perceive GEC and adapt food systems accordingly. Biophysical and socioeconomic vulnerability contribute to the overall human vulnerability to GEC.

Biophysical vulnerability

Current biophysical limitations to crop production are often modelled using climate and land resource databases. For example, the agro-ecological zone methodological framework adopted by the International Institute for Applied Systems Analysis integrates climate, soil type and terrain, and land-cover characteristics, together with a crop growth model, to estimate potential crop productivity. Constraints to various types of crop production can be identified (for example, rainfed crop production; Figure 2) and the approach allows for the incorporation of factors such as climate change and soil degradation in future scenarios. Figure 3 brings together three major factors which are likely to prove important constraints to future crop production, and thereby increase biophysical vulnerability: climate (with an example of change in minimum temperature; Figure 3a); fresh water supply (Figure 3b); and human-induced land degradation (Figure 3c).

Simulations with global climate models (GCMs) allow estimates of future climate which indicate that the following are all very likely changes in the 21st century:

- higher maximum temperatures and more hot days over nearly all land areas,
- higher minimum temperatures, fewer cold days and frost days over nearly all land areas,
- reduced diurnal temperature range over most land areas,
- increase of heat index over land areas, and
- more intense precipitation events.

Figure 3a shows, as an example, the projected change in the 20-year extreme minimum temperature between ~1995 and ~2025. Large changes are anticipated where sea-ice is reduced or lost, e.g., in the Arctic and Antarctic, and where snow cover is lost in winter. Significant reductions in cold extremes are also anticipated over most northern land areas, particularly central and eastern North America, central Europe and eastern Asia.

Wallace (2000) produced a summary of the global picture of water scarcity (defined as a *per capita* water availability of 1000 m^3 per year) now and in 2050. This demonstrated that, at present, around 7% of the world's population lives in areas where there is some degree of water stress. The areas of most acute water shortages are in North Africa with some water scarcity throughout southern Africa and the Middle East. When the same annual renewable freshwater resources are divided amongst the projected world population in 2050 (Figure 3b), the prediction is that around one in six of the Earth's population will have insufficient water to meet requirements beyond essential needs for drinking and food preparation. This situation will extend over large regions of Africa and the Middle East. Other areas with currently sufficient water will experience some degree of water shortage, e.g., India, the Far East and parts of China. In 2050 as much as two thirds of the global population may experience shortage of water, ten times the number of people who are in this situation today.

Although the above analysis contains gross assumptions about *per capita* water requirements and further assumptions about the proportion of total food production from irrigated agriculture, it usefully highlights:

- the size of future global water scarcity
- the major role of population growth and economic development in future water scarcity (see also Vorosmarty *et al.* 2000 who reached a similar conclusion).
- the importance of agricultural water requirements.

Human-induced land degradation relates principally to erosion by water and by wind, nutrient loss and salinisation. All four aspects can have major negative impact on both crop productivity in a given location, and on off-site aspects such as water and air quality. While generally site-specific in nature, land degradation is very widespread with large areas in developing country regions affected (Table 3). This is well demonstrated by the Global Assessment of Human-induced

Table 3. *Areas (Mha) of different developing country regions moderately, severely or extremely affected by various types of human- induced land degradation (from Oldeman* et al., *1990).*

Type	Land Area		
	Africa	Asia	South and Central America
Water erosion	170	315	77
Wind erosion	98	90	16
Nutrient loss	25	104	3
Salinisation	10	26	-

Table 4. *Indicators of human insecurity (from Lonergan* et al., *2000).*

Indicator	Component	Measure of component
Environment	Net energy imports	% of commercial energy use
	Soil degradation	Tonnes per year
	Safe water	% of population with access
	Arable land	Hectares per person
Economy	Real GDP per capita	US$
	GNP per capita growth	Annual %
	Adult literacy rate	% of population 15+
	Value of imports and exports	% of GDP
Society	Urban population growth	Annual %
	Young male population	% aged 0-14 of total population
	Maternal mortality ratio	Per 100,00 live births
	Life expectancy	Years
Institutions	Public expenditure on defence versus primary and secondary education	% of GDP
	Gross domestic fixed investment	% of GDP
	Degree of democratisation	Scale 1 – 7
	Human freedoms index	Scale 0 – 40

Soil Degradation (GLASOD) which shows not only the spatial extent of the problem but also its degree of severity (Figure 3c). Although the analysis suffers from small scale, has a limited number of attributes and is based on qualitative "expert judgement", it does highlight regions where land degradation is particularly serious and may have a significant impact on food production. As expected, regions of high population density often suffer from high or very high degrees of land degradation, which will have major bearing on the ability to produce food. A more detailed analysis has now being conducted for South and South East Asia (van Lynden and Oldeman, 1997), but analyses are needed for other regions, preferably at national level.

Socioeconomic vulnerability

Indicators of socioeconomic vulnerability often include some elements of the environment as well as indicators which probe various aspects of human livelihoods and well-being. Figure 4 brings together three elements of socioeconomic vulnerability: an index of human insecurity (Figure 4a); an estimate of populations inhabiting areas where the growing period is too short to allow crop production (Figure 4b); and the effects of projected climate change on potential production of rainfed cereals (Figure 4c).

Human security is a concept that recognises the inter-linkage of environment and society and is achieved when and where individuals and communities:

- have the options necessary to end, mitigate, or adapt to threats to their human. environmental, and social rights,
- have the capacity and freedom to exercise these options, and
- actively participate in attaining these options

Table 4 details the environmental, economic, societal and institutional components used to determine an index of human insecurity (Lonergan *et al.* 2000) which were quantified using published data for the years 1970 to 1995. This index includes a wide range of issues that go well beyond issues of food provision. The data were standardised such that all indicators were given the same weight in the composite index and the mean of all indicators calculated for individual countries within a range of one to ten; the higher the index, the greater the insecurity. Figure 4a shows the index for 1995, and illustrates the economic, social and political inequities which define the differences between the developing and developed world. Countries throughout Africa and southern Asia are already relatively insecure and this human insecurity, if not improved, may adversely affect their capacity to respond to future stresses including GEC. This is in contrast to North America, Europe and industrialized parts of Oceania where human insecurity is of less concern and signals a stronger capacity to adapt to future changes.

A major factor affecting human vulnerability in some areas is the length of the growing season for crops. Areas which are either too dry or too cold restrict the growing season and if this is less than 90 days it is normally impossible to grow a cereal crop to maturity. Figure 4b shows the distribution of people in areas where the length of the growing period is <90 d. Overall, 440 million people live in such areas (excluding irrigated areas). Few live in the cold north or in central Australia, but there are substantial numbers in the northern and southern margins of the Sahara, the southern Gobi desert, in central Asia, Peru and northern Mexico. The livelihoods of these people have to come mainly from sources other than rainfed cropping.

Recent studies of the effects of predicted climate change on rainfed cereal yields also demonstrate the differential vulnerability of different regions (Fischer *et al.* 2001). In this analysis, climate predictions in 2080 have been obtained from GCMs and assessments made based on current populations and socioeconomic conditions. Figure 4c shows that cereal producing regions of Canada and northern Europe and Russia might expect to increase production as a consequence of climate changes predicted by GCMs while many parts of the world will suffer losses including the western edge of the USA prairies, eastern Brazil and Western Australia. Overall, the results suggest that climate change will benefit the developed countries more than the developing countries even if cropping practices evolve to allow more than one rainfed crop per year. Moreover, the anticipated demographic growth and socioeconomic development in these developing countries will result in substantial increases in food requirements thereby exacerbating the detrimental effects of climate change.

GEC and vulnerability

The foregoing examples shown in Figures 3 and 4 demonstrate both the range of issues that might affect the vulnerability of food provision and the geographical diversity of the importance of individual factors. While changes in temperature are likely to be greatest in northern latitudes, future shortages of water and current degradation of soil resources are particularly important in much of Africa, the Middle East and South and East Asia. So, the impact of GEC is likely to be most acutely felt in parts of the world with many of the least developed economies. This, coupled with the high socioeconomic vulnerability of many of the same regions is also likely to limit the ability of societies to adapt in a timely manner to the changes that are anticipated. In particular, the adaptive ability of Africa with its high biophysical vulnerability, its relatively large population living on the edges of areas with an adequate growing season, and its relatively weak political institutions, must be of concern.

If GEC affects potential crop production in the diverse ways illustrated by Figure 4c, then a variety of adaptative responses will undoubtedly follow leading to modifications to current systems of food provision with concomitant feedbacks on the environment at national, regional and global scales.

Impacts, adaptation and feedbacks: development of a new science agenda

Many research groups are active in the general area of food "security" but their activities generally focus on current impediments to access to food. A structured approach, building on ongoing studies but emphasizing GEC issues, is needed to deliver an efficient research mechanism to address the rapidly emerging "GEC-Food" agenda. The International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the World Climate Research Programme (WCRP), all sponsored by the International Council for Science (ICSU), already encompass broad research agendas in these three major areas. They have now launched a new, interdisciplinary research project on GEC and food provision (Global Environmental Change and Food Systems – GECAFS) that combines biophysical and socioeconomic approaches. Its research agenda is broader than impact studies alone (important though these continue to be) and explicitly includes research on how food provision systems might be adapted to the additional impacts of GEC, and the consequences of different adaptation strategies for socioeconomic conditions and environment. By including both "impacts" and "feedbacks" in the context of food provision a niche for new research is clearly defined.

The goal of GECAFS is to determine strategies to cope with the impacts of GEC on food provision and to analyse the environmental and socioeconomic consequences of adaptation. It is being developed within the context of three "fundamental questions" of interest to science, development and society:

- Given changing demands for food, how will GEC additionally affect food provision and vulnerability in different regions and among different social groups?
- How might different societies and different categories of producers adapt their food systems to cope with GEC against the background of changing demand?
- What would be the environmental and socioeconomic consequences of such adaptations?

These three fundamental questions set the scope for three inter-related science themes:

Theme 1: Vulnerability and Impacts: Effects of GEC on Food Provision
Theme 2: Adaptations: GEC and Options for Enhancing Food Provision
Theme 3: Feedbacks: Environmental and Socioeconomic Consequences of Adapting Food Systems to GEC.

These inter-related science themes highlight a clear niche for the project, namely as a well-defined, interdisciplinary project addressing the relationships between GEC and food provision; and specifically stressing the additional complications GEC may bring to meeting demand, at a range of levels from regional to global. The diagrammatic relationship between the three Science Themes is shown in Figure 5.

In addition to addressing the three fundamental questions, GECAFS addresses the embedded question "what are the management and institutional contributions that can be used to help develop policy which maximises the effectiveness of adaptations?" This approach has been employed because it provides an explicit foundation for developing research projects that can identify the effectiveness of alternative policies at different points within food provision systems.

GECAFS – policy relevant scientific research

GECAFS research has been conceived to address issues of interest to development and to society at large, as well as to science. An innovative, three-way dialogue between policy-makers, donors and scientists is being established to develop research agendas which are useful in policy formulation, scientifically exciting and fundable. By designing GECAFS research in close consultation with "end users", and maintaining this link throughout the research process, the adoption of research findings are more likely because the agenda will have been set, in part, by the groups for whom the research is ultimately undertaken.

GECAFS is a new approach to global change science. New areas of science often develop at the boundaries of supposedly separate sciences and the juxta-positioning of social, economic, climate and biophysical sciences in GECAFS has exciting potential. Building on the underpinning science of the three sponsoring Programmes, GECAFS offers prospects for significant advances from its interdisciplinary approach. The three inter-related science themes provide an innovative framework within which new areas of science can be developed and harnessed to address the concerns of society. Examples of new areas of science in GECAFS include:

- Methods for the analysis of environmental and socioeconomic tradeoffs in food systems.
- Analyses of changing human wealth and food preferences and interactions with biophysical models of GEC to produce new insights of regions where food provision may be sensitive to GEC.
- Methods to allow the appropriate level of aggregation of small-scale food production systems and disaggregation of global-scale scenarios and datasets to address regional- and sub-regional issues.
- Comprehensive scenarios of future socioeconomic and environmental conditions.
- Use of past records of social adaptations to biophysical changes to provide inputs to scenario-based models of the future.
- New analyses and insights into the institutional factors which can reduce societal vulnerability to GEC.
- Developing combined socioeconomic-biophysical indices of vulnerability.

GECAFS is now consulting with regional policy makers in various parts of the world to develop research projects that are responsive to societal needs. An example of this work is provided by an emerging study in the Indo-Gangetic Plain (IGP). The food system in the IGP is largely dependent on rice and wheat grown in rotation (Timsina and Connor, 2001). However, there is growing evidence of overall yield stagnation and that the productivity of the system (especially the rice component) is even declining in some areas. An assessment of 11 long-term rice-wheat experiments (ranging from 7-25 years in duration) from the region indicates a marked yield decline of up to 500 kg ha^{-1} per year in rice in nine of the experiments (Duxbury *et al.*, 2000). Continuation of these trends will have serious implications for food provision, local livelihoods and the regional economy. As a given season's weather is a major determinant of yield (due to both the direct effects on crop growth and indirect effects related to management), there is concern that changes in climate, especially related to changes in climate variability, will exacerbate the observed trend. The potential for more extreme weather events has been highlighted by the IPCC (2001). Moreover, other analyses (e.g. Grace *et al.*, 2001) show that the highly-intensive production approach currently practised in large parts of the region is a major source of greenhouse gases, while the current irrigation practice is having serious negative effects on local water tables and water quality.

As the IGP food system is both threatened by global change and contributes to further change, research is needed to help develop policy and agronomic strategies to (i) sus-

tain production, especially in the face of potential increased climate variability and degradation of land and water resources; and (ii) promote production systems which enhance environmental and socioeconomic conditions. Due however to the marked socioeconomic and biophysical differences across the region, a single approach is inappropriate.

The eastern region of the IGP is a food deficit region characterized by low productivity, low inputs of fertilizer and water, risk of flooding, poor infrastructure and an out-migration of labour. Interdisciplinary research will be developed to address questions in the context of GECAFS Themes such as:

Theme 1: How will climate variability affect vulnerability to flooding within the region?

Theme 2: What are the market opportunities and management options for diversifying crops (e.g. legumes, aquaculture) to make more effective use of flood and groundwater?

Theme 3: How will this affect crop intensification, diversification, labour migration, inter-regional movement of food grains and water quality and river flow?

In contrast, the western region is a food surplus region characterized by higher investment, high productivity, major use of fertilizers and groundwater for irrigation, and an in-migration of labour. Interdisciplinary research will be developed to address questions in the context of GECAFS Themes such as:

Theme 1: How will climate variability affect change in water demand for irrigation?

Theme 2: How can changes in water management (e.g. though policy instruments such as water pricing, and/or agronomic aspects such as alternative cropping, land-levelling) reduce vulnerability to climate variability?

Theme 3: What will be the consequences of changed water management on the local and regional socioeconomic situation; and on greenhouse gas emissions, water tables and land degradation?

Other GECAFS studies are proposed for the Caribbean, southern African rangelands, coastal fisheries, the Maghev region and the peri-Artic.

Concluding remarks

GEC will add to the already complicated task of food provision in the 21st century. Changes in demography and in the structure of demand for food will add to the environmental changes already occurring but the differential vulnerability of different groups within the world's population will result in geographically diverse consequences and feedbacks. GECAFS has been established to investigate the interactions between biophysical and socioeconomic factors affecting food provision in different regions of the world. The need for policy relevant research on GEC issues is urgent and will make a small contribution to Evans' recent call to action: "Feeding the ten billion can be done, but to do so sustainable in the face of climate change, equitably in the face of social and regional inequalities, and in time when few seem concerned, remains one of humanity's greatest challenges" (Evans, 1998).

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Figures

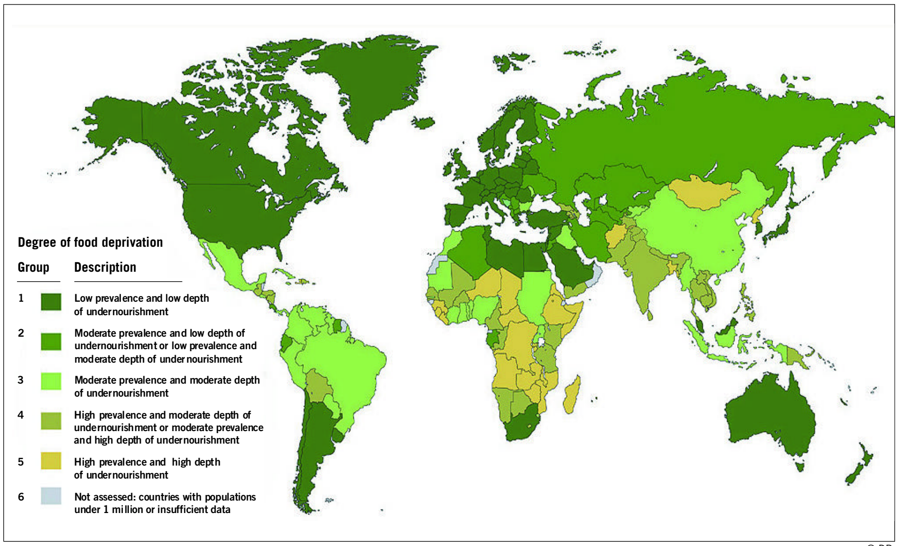

Figure 1.
Degree of food deprivation in 1996-98 (from FAO, 2000).

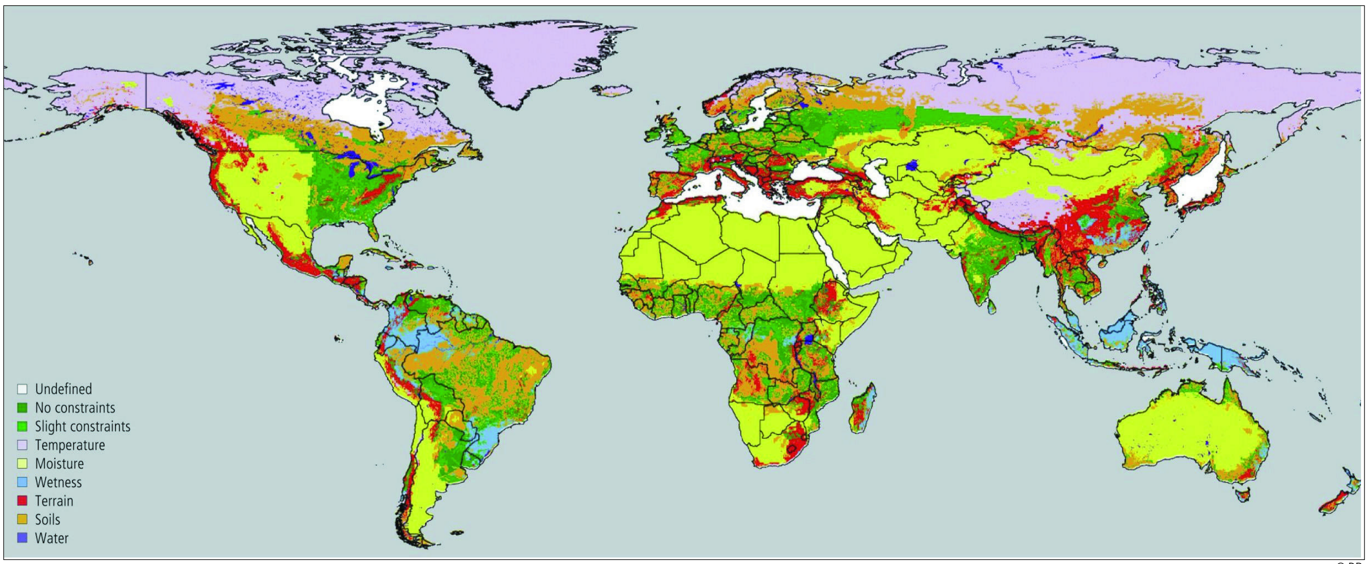

Figure 2.
Environmental constraints to rainfed agriculture (from IIASA, 2002).

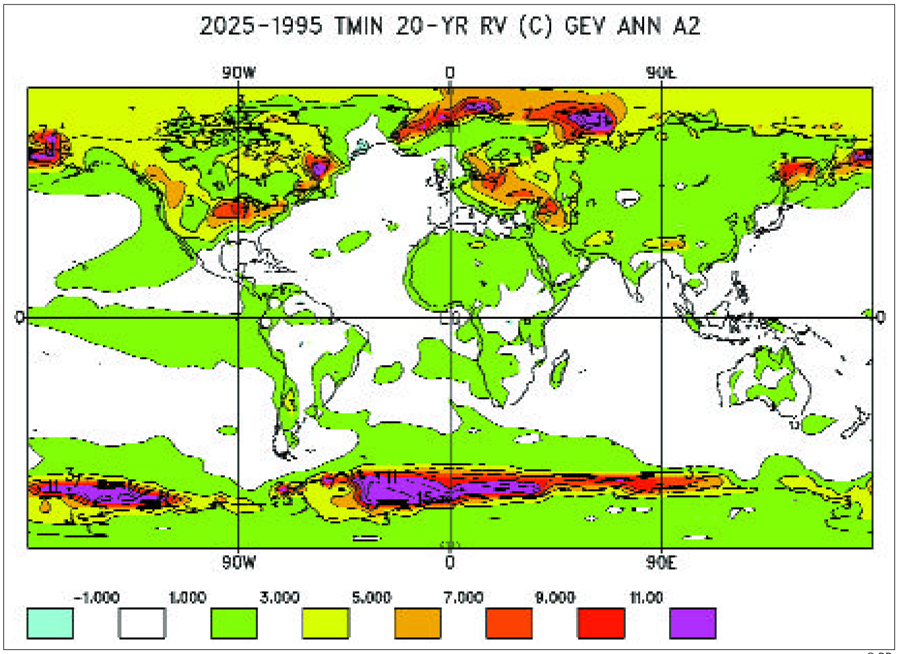

Figure 3a.
The change in estimated 20-year return values for extreme minimum temperature projected by the Canadian GCM2 between the decade of the 1990s and the decade of the 2020s. The colour scale is in degrees C. A 20-year return value for minimum temperature is the extreme minimum temperature that is expected to occur, on average, once every twenty years. (Figure provided courtesy of V. Kharin and F. Zwiers, Canadian Centre for Climate Modelling and Analysis, Meteorological Service of Canada.)

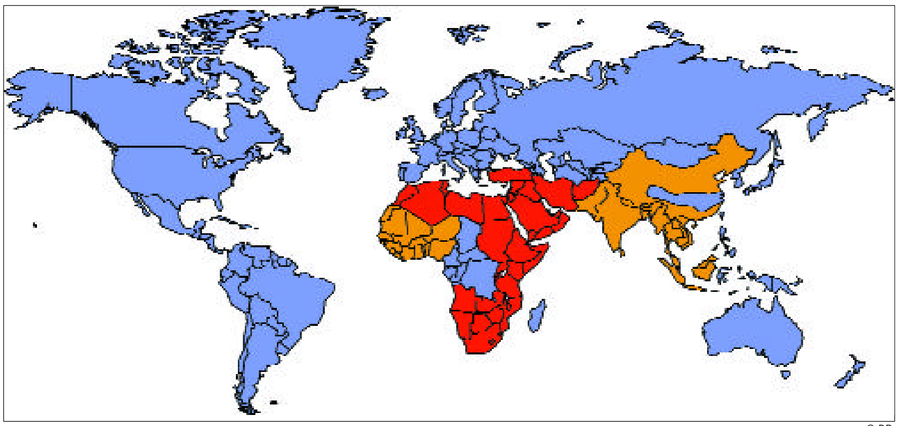

Figure 3b.
Estimated global water scarcity in 2050. Regions are coded according to their per capita annual renewable freshwater resource. Red- less than 1000 m^3 per person per year, orange- between 1000 and 2000 m^3 per person per year and blue- greater than 2000 m^3 per person per year (from Wallace, 2000).

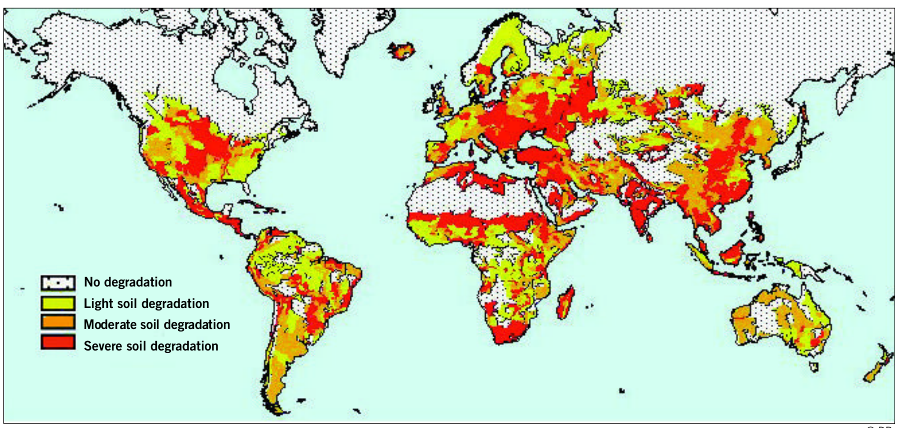

Figure 3c.
Results of the Global Assessment of Human-induced Soil Degradation (GLASOD) published by Oldeman et al., 1990.

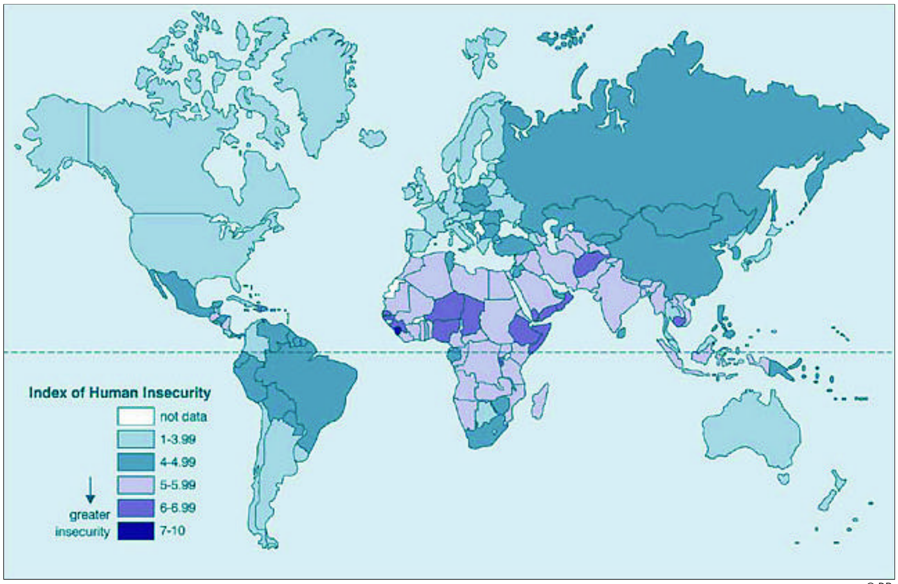

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Figure 4a.
Index of human insecurity (IHI) values for 1995 (from Lonergan et al., 2000).

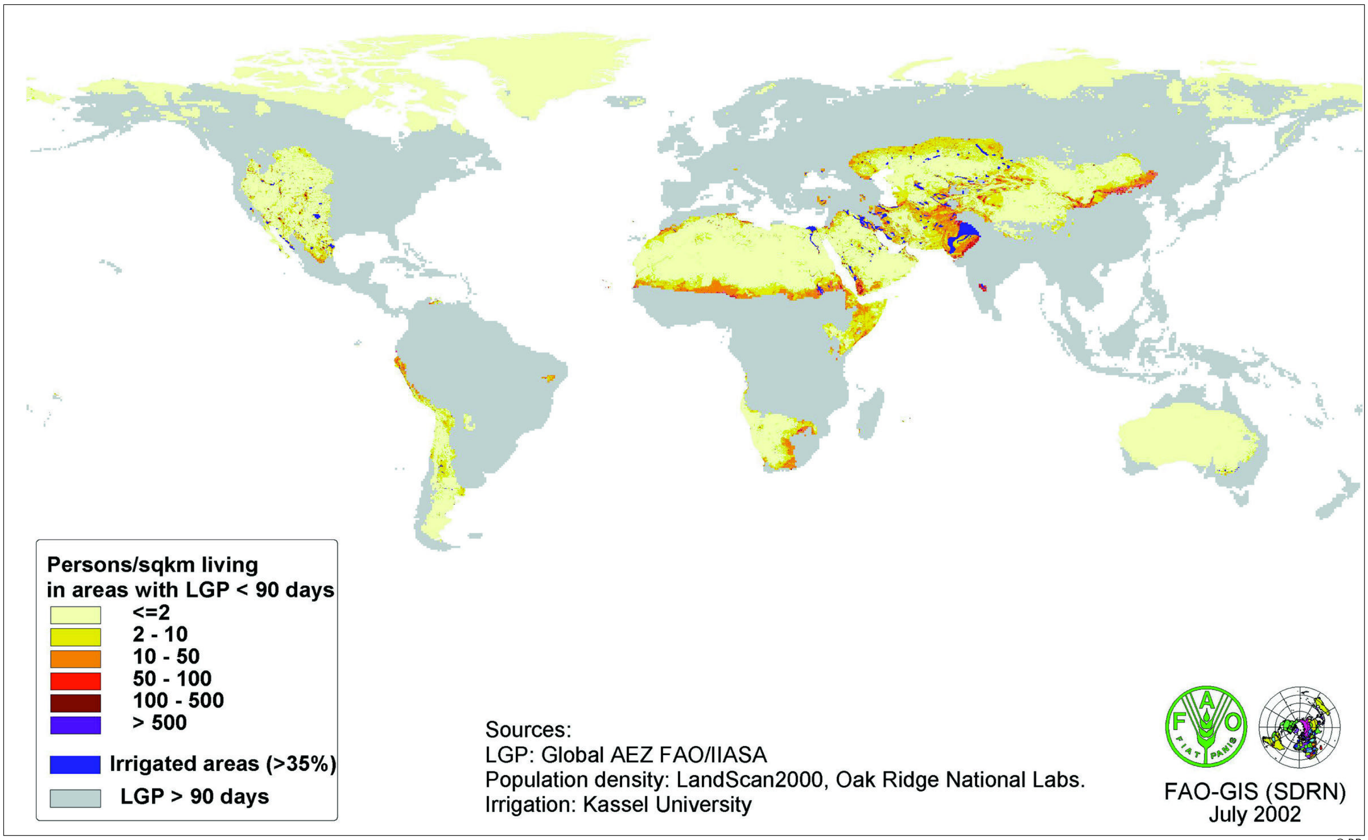

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Figure 4b.
Population density in areas where the length of the growing period (LGP) is < 90 days.

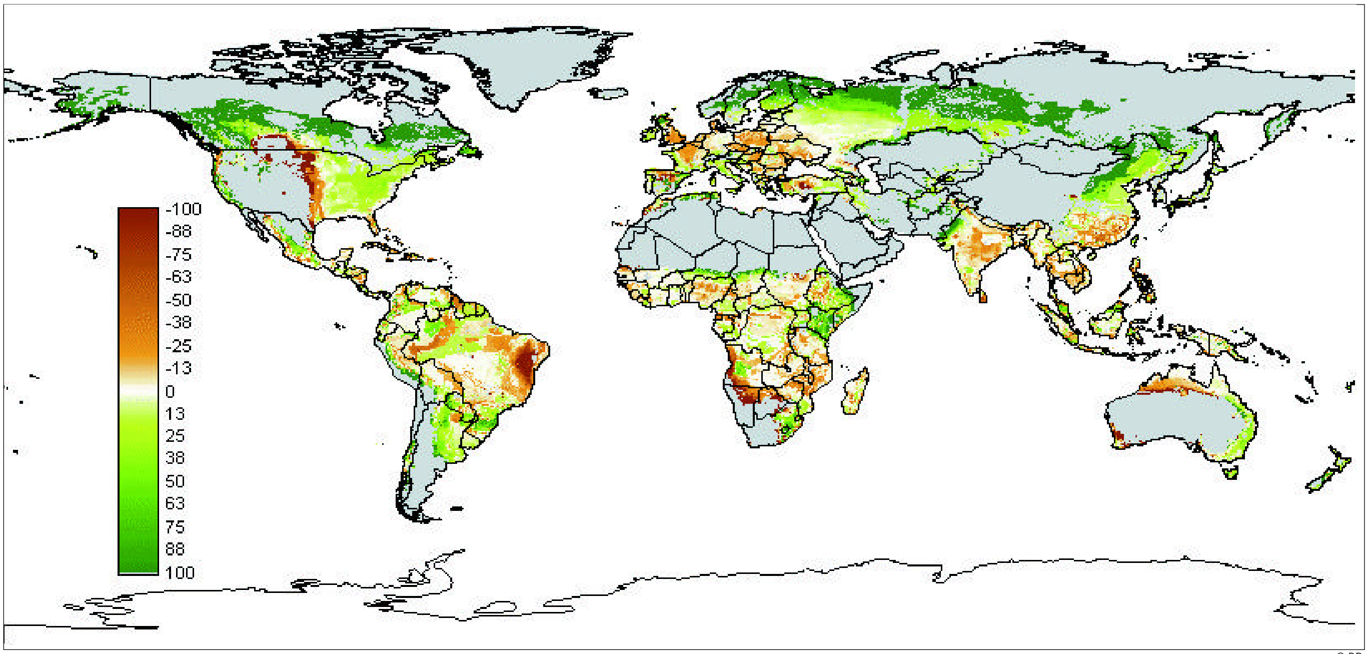

Figure 4c.

Projected impacts (% change) of climate change on multiple cropping potential production of rainfed cereals. Based on climate projections by the Max Planck Institute for Meteorology/ ECHAM4 2080 (from Fischer et al., 2001).

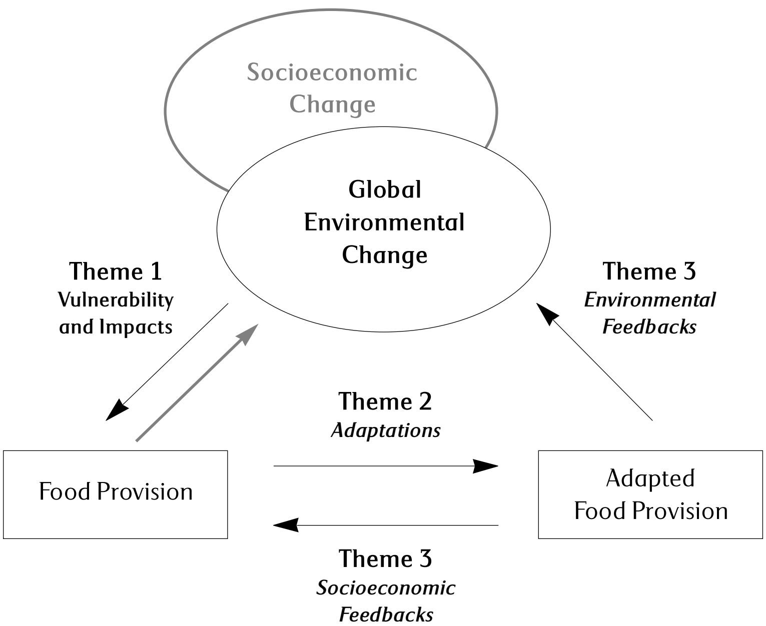

Figure 5.

Diagrammatic representation of the three GECAFS Science Themes with respect to GEC and food provision systems. The contextual issues of changing socioeconomic conditions and the consequences of current food provision systems on GEC are depicted in grey, while the main features of GECAFS are shown in black.

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