Climate Change : Agricultural and Forestry Research Activities in Canada

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ABSTRACT

The Canadian agricultural and forestry sectors are major contributors to the national economy. Both are highly sensitive to climate and climate variability and can be highly affected by relatively small changes. The prospect of climate change is perhaps the most serious issue yet to be faced by the agricultural and forest sectors in Canada. The combination of valuable agricultural and forest resources and possible major global impacts is what drives the climate change issue in Canada. Impacts are to be expected upon the ecology, protection, management and socio-economic aspects of each sector.

Forestry Canada as the lead federal agency has developed a comprehensive strategy for dealing with this issue. That strategy is discussed in the context of the major research activities underway relating to forecasting climate, forecasting forest responses, monitoring the change, mitigating the effects, and understanding the forest carbon balance.

Canadian research into climate - agriculture interactions is to a large extent a microcosm of international research efforts. The main research thrusts include initiatives relating to greenhouse gas emissions, crop modelling, agricultural adaptation to climatic change, and international programs.

INTRODUCTION

There now exists strong scientific consensus that global climate will change significantly over the next century as a result of increasing concentrations of greenhouse gases such as carbon dioxide, methane, nitrous oxides and chloroflurocarbons (Houghton et al., 1990, 1992). These gases are trapping a portion of the earth's infrared radiation and are expected to warm the planet by 1.5-4.5°. In response to this warming global precipitation patterns are also projected to change. Although there is general agreement on these conclusions there is large uncertainties in regard to the magnitudes and rates of projected changes at the regional scale.

Associated with these potential changes in the global climate are major changes in global ecosystems. Of particular importance to Canada are what the likely implications are for forest and agroecosystems which play a significant role in the economic activity of Canada. Work by a number of researchers suggest that agricultural and forest species ranges may shift significantly as a result of climate change corresponding to CO2 doubling. Work in forested ecosystems by Wheaton et al. (1987), for example, suggested that the southern boundary of the Canadian boreal forest could shift some 470-920 km north. Sargent (1988) projected that losses of potential boreal-forest sites in the Canadian south could amount to 170 million ha, while gains in the north could amount to 70 million ha. Therefore the net loss of climatically suitable area for boreal forest in Canada would be about 100 million ha. Rizzo (1992) work for major North American ecosystems suggests major shifts northward as a consequence of potential warming. Similar work by Bootsma et al (1984), Rosenzweig (1985) and Williams et al. (1988) show similar results for agroecosystems. Bootsma et al suggest that for every 1°C warming crop boundaries will shift northward by 100-175 km. Rosenzweig (1985) in examining the implications of the projected GISS climate change for North America wheat zonation suggests a shift in the winter wheat boundary north into Canada and the potential replacement of the current hard spring wheat cropping system. Similar conclusions have been drawn by Williams et al. (1988) and Stewart et al. (1990).

In spite of the above noted efforts there considerable uncertainty exists in regard to the implications of climate change for global and regional ecosystem responses and what these might translate to in terms of economic disruptions. Awareness of the issue of climate change has increased in Canada and its importance to the natural resource base in Canada. To address the various issues affecting the agriculture and forest sectors considerable research is being directed into climate change and variability work. This paper summarizes the major climate issues affecting the forest and

agriculture sectors in Canada and highlights the major areas of research currently underway.

FORESTRY

Sector Overview

In any discussion of climate change it is important to understand the implications in socio-economic terms. The following briefly outlines the importance of forest sector to the economy of Canada.

Forested land in Canada covered 453.3 million ha or 49.2% of the total land area (Forestry Canada, 1991). Of the forested land area productive timber occupies 243.7 million ha or 53.8% of the total. In terms of total biomass on nonreserved forest land Canada's forest contains an estimated 25.3 Gt or 24.2 billion m^3. Major tree species include spruce, douglas fir, pine, larch, cedar, poplar, hemlock, birch, beech, maple, and fir.

Timber harvest on an annual basis covers approximately 1 million ha in 1989 (Forestry Canada 1991). For industrial and fuelwood purposes this represents a production of 191.4 million m^3. This figure represents 83% of the allowable annual cut. British Columbia, Ontario and Quebec are the largest producers with a combined total of 79% of Canada's timber production. Softwood represents the largest percentage of Canada's timber production with a production of 174.6 million m^3 or 91.2%.

Forestry is a major industry contributing significantly to the economies of British Columbia and Eastern Canada, and to Canada as a whole. For example, in 1990, forest industries contributed $50.4 billion to the Canadian economy with the value of exports amounting to $22.2 billion (Forestry Canada 1991). In terms of exports 27% comes from newsprint, 28% from wood pulp and 24% from softwood lumber production. British Columbia, Quebec and Ontario are the major producing areas. Directly and indirectly, forest industries provide employment to 670,000 people, representing 1 out of every 18 jobs. Roughly 350 communities across Canada are economically dependent on forest industries for there existence.

Forestry Research in Canada

In Canada, forest research is carried out by federal and provincial governments, universities, forest companies, and privately and cooperatively funded institutions.

The Federal Department of Forestry plays a major role in Canadian forest management research. Operating across Canada in six regional forestry centres, two national forestry institutes, and seven regional sub-offices, (Figure 1), Forestry Canada carries out short and long-term, basic and applied research.

The focus of federal forestry research is to increase the productivity and competitiveness of the Canadian forest sector and to maintain the environmental integrity of the resource base. Forest management, protection and environmental quality are continuing priorities.

Climate Change Research

In relation to the climate change issue research has a vital role to play in assessing the implications of climate change on Canada's forest and in communicating this information to Canadians. Forestry Canada recognizing the implications of climate change for the Canadian forest sector developed a 5 point strategic research plan to address the issue of climate change (Forestry Canada 1990). In the plan, the following 5 major concerns affecting policy decisions were identified.

Effects of climatic change on the forest: Canada's forests are expected to be greatly affected by the changing atmosphere. Indirect impacts are likely to occur in relation to productivity, reforestation, harvesting, and losses due to fire, pest damage and extreme climatic events. Effects on wildlife, fisheries, recreation and indigenous peoples will be large and will have to be considered in adaptation and mitigation strategies.

Adaptation to climate change: Due to the nature of the problem, adaptation strategies will have to look at all aspects of the forest ecosystem, with harvesting, reforestation, utilization and protection practices. Other adaptations, not addressed in this plan, will involve wildlife, fisheries, recreation and human habitation; Forestry Canada needs to respond to and influence policies in these areas.

Impact of changing crops on forestry: Major shifts in the fibre resource will occur in the forest regions; shifts which can be predicted and for which adjustments can be made and for which technological improvements can be developed to ameliorate changes. These effects of climate change will have widespread economic implications and will require intensive forest management to alleviate the severity of the impacts.

Changing forestry values in changing sociological settings: Severe land use conflicts can be anticipated as a result of changes in agricultural and industrial development. Forestry Canada will be called upon to assist in developing projections for industrial

clients and for governments, and this information will not always be delivered with the backup of a high level of confidence in the scientific information.

International implications of the changing climate: Global climate change will also affect Canada's relationship with other producers in the international forest products market. The boreal forests can expand to some extent in Europe and in western Canada, but much more so in Siberia (USSR) and possibly China. This could cause major re-alignments in world markets. Canada's vast northland, made more attractive by the milder climate, may also appear more attractive for settlement by people displaced by changed conditions around the globe.

Forestry Canada responded to the above noted issues by developing and implementing a scientific program. The program's 5 major components include:

1. Forecasting the effects on forests of future climate using dendrochronological and paleo-ecological approaches;

2. Forecasting the response of forests through investigation of the physiology, genetics, ecology and stress response of forest trees;

3. Monitoring the change in forests as the effects become evident;

4. Mitigating the effects of change by developing methods to enable forest ecosystems to tolerate climate-induced stress;

5. Developing a Carbon Balance equation for the forest sector in Canada.

The following summarizes the highlights of research being undertaken in each of these areas.

Forecasting of Climate

Forestry Canada is developing data sets which can be used to help predict the effects of changes in climate. Two approaches to forecasting are being investigated.

The first approach relates prehistoric climatic changes to forest ecosystems and integrates the data into predictive models. At the Petawawa National Forestry Institute (PNFI) in Chalk River Ontario research is underway on the meteorological and climatological aspects of climatic change and atmospheric pollution and the decline of white spruce plantations is being investigated using a dendrochronological approach.

The second approach relates instrumented climatic changes to forest ecosystems and integrates the data into predictive models: At the Northwest Forestry Centre (NFC) in Edmonton, Alberta, paleo-ecological studies are assessing the effects of the mid-Holocene warm period on wetland dynamics and paleo-climatic parameters for the period are being derived. The ecoclimatic regions of Canada are being determined by succession and the ecological basis for analog regions supplied. They are using ecoclimatic provinces to assess the possible ecoclimates under doubled CO_2 concentration and to assess the implications for the boreal forest in the western interior.

The study of ecotones, where climate-induced changes are most easily observed, is also underway. Models are being constructed to predict changes in forest growth dynamics by evaluating current ecotone analogs to estimate climate scenarios and by evaluating past ecosystem changes related to past climate changes.

Forecasting the Response of Forests

How will the forests respond to the anticipated change and what are the basic parameters which drive that response? To answer these questions, process-oriented research is being conducted on tree physiology, factors controlling reforestation, variation in forest trees and effects of pollutants, fire, insects and diseases. The integration of these data to evaluate stress and forest decline is receiving increased attention in response to the demands for integrated forest management models.

Tree Physiology: Ecophysiological studies are underway on seedling water relations, photosynthesis and nutrition at the Newfoundland-Labrador Forestry Centre (NLFC) in St. John's, Newfoundland. There are more detailed studies ongoing at the Laurentian Forestry Centre (LFC) in Quebec City concerning the effects of frost on seedlings. These are complemented by studies on the influence of photoperiod on hardening-off, mineral nutrition and seedling stress. The field studies needed for process-oriented research, including survival and growth, state of evaporation in container seedlings, water relations in the field, levels of water stress, and the validity of moisture testing methods are also being established at LFC and several other regional forestry centres.

At the Maritimes Forestry Centre (MFC) in Fredericton, New Brunswick, the effects of increased CO_2 levels in greenhouses are being studied for inclusion in the development of process-based models.

Factors controlling reforestation: Reforestation studies are being conducted at most Forestry Canada research centres. These include: stand establishment, vegetation management, soil nutrient cycling

processes (NLFC); soil microbials, litter deposition, nutrient turnover rates (MFC); the effects of climate change on forest floor dynamics(PNFI); ecophysiology research on the nature of hardwood/softwood competition, weed control strategies and the problem of softwood establishment without the use of chemical herbicides is ongoing at the Ontario Regional Forestry Centre (FCOR) in Sault Ste. Marie, Ontario; studies are also underway on the environmental impact of forestry practices on forest sites at the Pacific and Yukon Forestry Centre (PYFC) in Victoria, British Columbia; and at the FCOR and NLFC, the effects of peatland drainage and the anticipated effects of climate change on peatlands are being studied.

Variation in forest trees: Long-term studies on species/provenance interactions with the environment are ongoing at NLFC, MFC, LFC, NFC and PNFI.

Provenance trials of commercially valuable species were initially established to examine the patterns of variation so that the best adapted strains could be used in reforestation programs. A constant pattern of climate was assumed, an assumption no longer valid. Provenance trials represent detailed knowledge of germplasm, selected 20-40 years ago and grown under conditions of changing climate. Most genotypes have been grown and monitored over long periods under known climatic conditions but quite different from their origin. This represents a unique opportunity for Forestry Canada to study the effects of changing climate on forest trees.

Breeding black spruce from different populations, and evaluating their response to climatic change is being done at PNFI. Studies include the genetic control of adaptive traits related to climatic conditions and the quantification of the potential for change in adaptive traits in response to natural and artificial selection. Genetic strategies to compensate for effects of climatic change on forest productivity are also being developed.

Effects of pollutants: At MFC, studies of simulated acid rain effects on cuticles, reproduction processes, interactions between pollutants in the atmosphere and forest trees are underway. Studies also include investigation of the relationship between acid fog and deterioration in birch stands and on red spruce decline in Northeastern U.S. and Canada. Effects of ozone and temperature changes on physiological and morphological variables in tree crowns of sugar maple are also being studied.

Damage to forests: Research is being done to develop fire behaviour prediction systems at the NFC and FCOR. At PNFI and FCOR studies are underway on the impact of a doubling of CO2 on the occurrence of forest fires. FCOR is also cooperating with Environment Canada and the University of Quebec-Montreal in developing a meso-scale climate model for inclusion in the Canadian

global climate general circulation model for use in assessing future fire risk.

Research on pathogens related to early establishment and tending of the current and future forest and on the environmental impact of forestry pesticides on forest ecosystems is underway at FCOR. Plantation pest management, integrated protection systems for insect pests and regeneration pest are being studied at PYFC. The environmental impact of forestry pesticides on forest ecosystems is being undertaken at the Forest Pest Management Institute (FPMI) in Sault Ste. Marie, Ontario.

Forest decline: Within Forestry Canada, forest decline work is concentrated at the LFC in Quebec and includes hardwood declines, effects of climatic stress on sugar maple and on nutrient cycling in relation to pollutants, evaluation of stresses and their effects separately on the forest, effect of climatic change on forest health and productivity, and the impact on climate change on boreal forests. Scientists are cooperating with the IIASA Study on the Impact of Climate Change on Northern Forests and their Boundaries. The projected impacts of climatic change on forest ecosystems and the techniques for forestry impact assessment of climatic changes are being studied at NFC.

At the PYFC, development is underway on biologically based mechanistic models for Douglas-fir ecosystems. As well, methods of assessing effects of silvicultural treatments on growth and yield for the purpose of improving forest management practices are being studied.

Monitoring the Change

The largest Forestry Canada activities in the field of monitoring are the Acid Rain National Early Warning System (ARNEWS) and the Forest Insect and Disease Survey (FIDS). These detect and monitor change in the health of the forest and damage from insects and diseases across Canada. These operations are done at the regional establishments and the database is centralized at the Petawawa National Forestry Institute. Research on insect population dynamics and response of insect populations to weather patterns are included in this category. The distribution of insect species is often limited by temperature and weather patterns and so changes here may presage changes in climate. It can be expected that the monitoring of insect pest distribution will be a major study with relevance to the climate change issue.

The occurrence and extent of fire is closely related to changes in temperature and moisture. The recent sharp increases in the area burned in Canada may presage the changes in climate projected by other methods and are being studied from that point of view. Research is underway on fire spread, behaviour and fuel loading to

provide data for fire prediction models.

New techniques developed at PNFI may be of great value in acquiring the data for monitoring change. Development of the Multi-spectral Electro-optical Imaging Scanner (MEIS) for the monitoring of forest vegetation in relation to climatic change and atmospheric pollution is a good example. In conjunction with remote sensing consultants, Forestry Canada scientist at MFC are developing image signatures to provide reference points for the study of changes in fog distribution, frequency and extent of birch browning. Betula cordifolia is a cool habitat species at the southern limit of its range in the Bay of Fundy area. Its distribution and phenology can be used as a biomonitor of climate change.

Mitigating the effects of climate change

Mitigation of the effects of climate change on forests will require the information derived from the Forestry Canada research program. Research on tree physiology will aid in the selection of better adapted plants for reforestation, ecosystem studies will aid in use of better techniques of site preparation, provenance trials will result in genotypes adapted to new and changing conditions, monitoring will help in developing a systems approach to management of the damage expected from higher temperatures and stressed forests.

At PNFI, the breeding of black spruce from different populations and study of adaptive traits has identified genotypes of black spruce particularly tolerant to drought. In Newfoundland, a small number of Sitka spruce genotypes have proved to be adaptable to climatic conditions quite different from that of their origin and there are indications that they are developing into a land race. These "straws in the wind" show that scientists may have very little idea of the range of natural variation in forest trees and consequently there is a great opportunity to develop new genotypes for new climate conditions.

Research in Forest Management Systems and improvements in establishment and tending are being developed at several establishments. The integration of data obtained over the last 50-80 years is essential to enable planners and policymakers to manage forests in the future.

The Carbon Balance

Forests play an integral role in the global carbon cycle. Canada as custodian to 10% of the world's forest could have a key role in reducing atmospheric CO_2 concentrations. The question is whether forests are part of the solution or part of the problem. To

address this issue Forestry Canada has a 3 phased carbon budget modelling project underway.

Under current management practices, Canadian forests are thought to be a small net carbon sink; but there is evidence that improved management could enhance this effect and thereby increase the size of the carbon sink attributable to Canadian forests. As a national research organization, Forestry Canada is developing information to test both these hypotheses.

An extensive research effort is underway within Forestry Canada to support and conduct research into biomass production, carbon budgets of forests and potential productivity of forest species. Within Forestry Canada work is underway to address a number of aspects related to the carbon balance including modelling of the carbon budget of Canadian forests; decomposition, absorption of carbon by peatlands; effects of elevated CO_2 levels on tree growth and productivity; and implications of fire. A number of these are linked with efforts being undertaken by other government agencies and universities, and international organizations and governments.

The development of a carbon budget model for Canadian forests is being undertaken by Forestry Canada's Ecosystem Modelling Group at the NFC in Edmonton, Alberta. The major objective of this process based modelling research is to provide a method for estimating and assessing the productivity of the boreal forest. The model is being designed to enable researchers to determine the vulnerability of the boreal forest ecosystem to climate change, and to evaluate various forest management options that might be used to counter potential unwanted effects. Results of the modelling work are detailed in a number of publications including Apps and Kurz (1991, 1993), Kurz et al. (1992) and Price and Apps (1993). Currently the sensitivity of the Phase I model results to changes in disturbance rates, model assumptions and data inaccuracies is being evaluated. As well, investigation of a number of resource management and forest product alternatives (including bioenergy substitution for fossil fuels) are now underway.

AGRICULTURE

Sector Overview

The Canadian agriculture and food sector is of considerable importance to the Canadian economy and a major contributor to international export markets. Collectively, the agri-food industry:

- provides employment for about 25% of the Canadian workforce,

- accounts for about 13% of gross national product,
- exports between $8-10 billion of goods annually, and
- accounts for a trade surplus of between $2-4 billion annually.

A relatively harsh climate and unsuitable soils impose considerable restrictions on the location of Canadian agriculture. Land in agriculture accounts for about 13% of the total land base within Canada's 10 provinces. The area of land that is physically capable of sustaining field crop production is limited to about 45 million ha, and only about half of this area is classed as prime agricultural land (i.e. Class 1 and 2 soils). The agriculture land area has remained relatively stable over the last few decades, but agricultural land use has been intensifying and there has been substantial increases in total cropland area. Furthermore, present agricultural land reserves are characterized by marginal climates and remote locations relative to markets and the infrastructure underpinning the sector.

The Canadian agricultural system is highly diversified, reflecting the extent to which resource endowments, infrastructure and markets conditions vary throughout the country. In the Atlantic provinces, agriculture is of regional importance, and livestock, dairy, poultry and potatoes are the major agricultural commodities. Agriculture in Central Canada benefits from many advantages including superior soils and climatic conditions, proximity to urban markets and highly developed processing and transportation sectors. The region's agricultural sector is diversified, and is a major producer of livestock, field crop and vegetable commodities. In the Prairie provinces the agri-food industry is a major component of the regional economy. For example, in Saskatchewan agriculture accounts for about 16 per cent of the provincial gross domestic product, the highest percentage of any Canadian province. Spring wheat is the main commodity and the majority of each year's crop is destined for export markets. In British Columbia agriculture is a relatively small industry focusing on dairy, poultry, vegetable and fruit production.

Canadian agriculture is also a major supplier to the international agricultural market. Wheat is the main export product, and Canada is one of the top 3 wheat exporters. Annual wheat exports from Canada averaged 18.6 million metric tonnes during the last half of the 1980s, representing about 19% of total global wheat exports. Aggressive export subsidy programs in the USA and Europe have been driving international prices for wheat downward. This in turn has adversely impacted Canadian wheat producers, and the extent to which Canada can continue to be a major supplier of wheat to international markets is being questioned. In recent years, there has been significant diversification in Canadian agricultural exports, with significant increases in exports of red meats, dairy products, animal genetics and vegetables.

Development of Climate Change - Agriculture Research in Canada

The growing consensus developed during the 1980s that human activities were altering the earth's climate sparked considerable interest into the implications of potential global climatic change for Canadian agriculture. Current agro-climatic conditions for many regions in Canada are characterized by relatively short frost-free periods, and therefore it should not be surprising that much of the Canadian research into the agricultural impacts of global warming has focused on possible alterations in the growing season properties for annual crops with concomitant adjustments to productivity levels (for example, see Bootsma et al., 1984; Brklacich and Smit, 1991; Singh and Stewart, 1991; Smit and Brklacich, 1992; Stewart, 1990; Williams et al, 1988).

Both university and government institutions were actively involved in these research programs generating a number of useful studies that provided relative measures of the sensitivity of specific agricultural attributes (e.g. change in frost-free season, productivity responses to selected climatic changes) to altered climates. However, inconsistent research design and incomplete spatial and sector coverage has hindered the development of a national perspective.

Canadian research into climatic change and agriculture has been similar to this sort of research elsewhere. The research field was expanding rapidly during the 1980s and emphasis was placed on investigating first order or direct impacts stemming from an altered climate. Much of this research was:

- limited to only a 2 X CO_2 induced climatic change,
- considered changes in climatic averages only,
- considered climatic changes in isolation, and
- employed comparative static approaches,

Overall the agriculture-climate change investigations of the 1980s represent the first generation of research in this field and, as is often the case with rapidly developing fields of investigation, assessments of the strengths and weaknesses of the previous studies followed. These appraisals have suggested many avenues to advance the agriculture and climate change field of research, including consideration of:

- changes in climatic variability as well as averages,
- climatic change scenarios based upon scenarios other than a 2 X CO_2 atmosphere,
- the impacts pathway,
- possible responses to climatic change (mitigative and adaptive responses),
- agriculture's potential to be part of the solution,
- the combined impacts of climatic change and elevated CO_2

levels, and
- climate impacts vs changes in other biophysical and socio-economic conditions.

In addition to the research activities related directly to climatic change and agriculture, two other major federal government initiatives have had and continue to have considerable influence on climate change - agriculture research. Agriculture Canada initiated in 1989 a policy review of all policies and programs under its jurisdiction. This review process led to formal commitments to support environmentally sustainable agricultural practices and much of the climate-related research is now conducted under this broader umbrella. The Government of Canada's Green Plan, which was established in 1991, reinforces the federal commitment to sustainable development and is presently supporting several programs and projects relating to climate change and agriculture research. The Green Plan is a 6 year, $3 billion initiative under which most federal climate change research is now being undertaken.

Current Research Programs and Projects

Research into climatic change continues to develop in Canada and the main research thrusts of current programs include initiatives relating to greenhouse gas emissions, crop modelling, agricultural adaptation to climatic change, and international programs.

Greenhouse Gases Initiatives

Organic matter in the world's soils contains about 3 times as much carbon as terrestrial vegetation (Schlesinger, 1986). The large size and relatively long residence time of soil carbon make soil carbon an important component of the global carbon cycle. Human activities such as land clearing, livestock production and land cultivation can lead to reductions and increases is soil carbon, and thereby alter atmospheric concentrations of greenhouse gases. It is now widely recognized that Canadian agriculture has two vital roles to play in meeting national objectives for greenhouse gas (GHG) emissions: reductions in emissions and carbon sequestering.

Agriculture Canada is currently compiling a soil carbon data base at a scale of 1:1 million for all of Canada (Agriculture Canada, 1993). The data base will be georeferenced and linked to the National Soil Data Base. The information is be used to assess present carbon levels in Canadian soils and to provide basic data for use in process-oriented models designed to estimate the impacts of human activities on soil carbon dynamics.

The Climate Change - Reducing the Uncertainties Program is a federal interdepartmental initiative that is being led by

Environment Canada and funded under Canada's Green Plan. Agricultural components of this initiative are managed by Agriculture Canada and collectively designed to reduce uncertainties about the spatial distribution and temporal dynamics of sources and sinks for GHG emissions(Agriculture Canada, 1992a and 1992b). This program is broken into 3 main components:

- Process Level Experiments
- Ecosystem Level Experiments and
- Integration Experiments

Process Level Experiments: The broad aims of this component are to identify and define GHG sources and sinks, investigate GHG production and consumption mechanisms, and characterize factors influencing the dynamics of these processes. Specific studies are attempting to quantify CH_4 generated by enteric fermentation and agricultural wastes; identify soil mechanisms of N_2O production, emission and absorption; evaluate techniques for reducing CH_4 and N_2O emissions from livestock manure; enhance techniques for measuring CO_2 fixation efficiency; and improve understanding of variables that effect soil carbon storage.

Ecosystem Level Experiments: This component is based on representative agroecosystems throughout Canada with the broad objectives of assessing the net balance for the 3 main GHGs and determining the feasibility and effectiveness of prospective ameliorative management techniques. The focus is on measuring and understanding GHG exchanges and developing mathematical expressions of major physical, chemical and biological processes involved in GHG production that occur with major land use practices. Specific studies are investigating the net carbon balance for selected agroecosystems; assessing the net contribution of dominant Canadian agroecosystems to atmospheric N_2O and CH_4; identifying and comparing prospective management that encourage conversion of atmospheric CO_2 to stable soil organic matter; comparing the effects of alternative fertilizer practices on N^2O evolution; and comparing the effectiveness of alternative methods for reducing CH_4 emissions from enteric fermentation and animal wastes.

Integration Experiments: This component is designed to develop and improve methods for scaling-up agroecosystem estimates of GHG sources and sinks to regional and national scales. Specific studies are utilizing GIS technologies and existing soil and environmental data sets to determine whether major agroecosystems are net GHG sources or sinks; and measuring GHG fluxes along selected transects over broad regions as a means to validating and improving regional models.

Crop Modelling Initiatives

The application of crop models to climate change issues continues to evolve in Canada. A number of scientists have been experimenting with the CERES family of models. This includes efforts to:

- consider the combined impacts of elevated CO_2 levels and climate change on crop growth and yields (Brklacich and Stewart, 1993),
- refine winter kill algorithms for winter crops and apply these models to climate change issues,
- apply crop models in areas that are currently beyond the agro-climatic margin (Brklacich, 1993) and
- link insect and pest models to crop growth models (McNaughton, 1992).

Overall, these activities employ similar research strategies to earlier research into crop yield responses to altered climates (i.e. a climatic change scenario is specified and crop yield sensitivities to the altered climate are investigated), but analytical methods are constantly being refined and the range of crops and spatial coverage is being expanded.

Climate Adaptation Initiatives

The climatic change and impacts research fields have undergone a substantial change since work was begun in the early 1980s. Reviews and appraisals of climatic change-related research conducted under the aegis of the Intergovernmental Panel on Climatic Change (IPCC) first assessment (Houghton et al. 1990; IPCC, 1991; Teggart, 1990) and other related research leading up to the 1992 Earth Summit in Brazil focused on prevention of global climatic change with little to no attention being devoted to the prospects for adapting to a changing climate. The underlying arguments for this approach usually stressed that consideration of adaptive strategies could be interpreted as an admission that climate change was inevitable and thereby undermine attempts to reduce GHG emissions.

In the past year, there has been considerable re-evaluation of this position. As a result, the need to simultaneously consider mitigative and adaptive strategies has been gaining acceptance. The re-organization of IPCC Working Groups II and III is an explicit recognition that climate adaptation initiatives must be part of a broadened research agenda.

The inclusion of adaptive strategies within agriculture and climatic change research activities in Canada has been evident and is gaining momentum. Some of this research has focused on the

recent past as a means to obtain a better understanding of strategies that Canadian farmers currently employ to ameliorate the impacts of climate variability. This includes empirical analyses of farmer perceptions and responses to specific events such as the 1988 drought and to longer term (i.e. several decades) climate variability (Wheaton and Arthur, 1989; McNaughton, 1992).

Adaptation to climate variability and change is still an evolving research field and several agencies are participating in its development. Environment Canada (1993) has recently commissioned a Task Force on Climate Adaptation to demonstrate the importance of climate adaptation, assess policy implications and to identify research priorities. Under the previously mentioned Climate Change - Reducing the Uncertainties initiative, Agriculture Canada is supporting a research project aimed at improving methods for assessing the prospects for adaption by the Canadian agricultural sector to global climatic change.

International Initiatives

Canadian scientists have recognized for some time that the impacts of global climatic change could have considerable effects on adjustments in comparative advantage and on international agricultural trading patterns. Research conducted under the aegis of the Land Evaluation Group at the University of Guelph (Land Evaluation Group, 1987; Smit et al, 1989) assessed the implications of global warming for Canada's comparative position in agricultural production and trade. Elsewhere, Williams et al (1988) provided a Canadian contribution to the IIASA led study into the regional impacts of climatic change on agricultural production (Parry et al, 1988). Most recently, Canada contributed to an investigation co-ordinated by the US Environmental Protection Agency (EPA) and Agency for International Development (AID) into the implications of a potential global warming on international trade of agricultural commodities (Parry and Rosenzweig, 1993). The international project focuses on the trade patterns among nations, and contributing nations were requested to appraise the impacts of a range of scenarios for global warming on production opportunities for a major export or import crop. In addition, the Canadian Global Change Program in collaboration with IGBP organized the 1992 international symposium on the Effects of Global Change on Wheat Eco-Systems.

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