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Agriculture, Forestry, and Other Human Activities

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AGRICULTURE, FORESTRY, AND OTHER HUMAN ACTIVITIES

EXECUTIVE SUMMARY

INTRODUCTION

Existing forests serve a multitude of functions vital for mankind in addition to providing wood as a renewable resource. Thus, there is a paramount need to conserve forest resources and to implement measures to increase forest biomass at the same time.

The total area of forests (excluding other wooded lands) at present amounts to about 4 billion ha, roughly half of it tropical forests, and of the remainder, temperate and boreal forests account for one third and two thirds respectively. During the course of human history, roughly 2 billion ha have been lost due to various human activities, mostly in the temperate zones.

The amount of carbon presently stored in forests is equivalent to about the amount in the atmosphere, namely, approximately 700 billion tonnes of carbon. This means that 1 ha of forest contains on a global average between 100 and 200 tonnes of carbon, while afforested areas may fix on average 5–10 tonnes carbon per ha per year. Land uses involving conversion of forests through burning of biomass or felling contribute about 9 percent of total carbon equivalent greenhouse gas emissions, and about 15–30 percent of anthropogenic CO_2 emissions. Agricultural production systems provide both sources and potential sinks for atmospheric greenhouse gases. It is estimated that agricultural activities currently contribute about 14 percent of total carbon equivalent of greenhouse gas emissions, including emissions of carbon dioxide, methane, and nitrous oxide, and emissions of gases that contribute indirectly to global warming, such as nitrogen oxides and carbon monoxide.

World population is projected to grow at an average of 1.3 percent per year reaching about 8.2 billion by 2025. To meet the increased food requirements, agricultural production will also need to increase. Agricultural crop area in developing countries is expected to grow by 1.2 percent per year in combination with increased yields from existing crop acreage obtained largely from increased use of nitrogen fertilizers. Production of meat and dairy products is expected to increase by over 45 percent in this period. Achievement of food production requirements is and will remain the dominating goal in many areas around the world, and actions in response to climate change must recognize economic and social impacts in addition to environmental considerations.

Organic matter in waste and wastewater is converted into methane by various types of methane bacteria under anaerobic conditions. Anaerobic conditions exist in most landfill sites and in most lagoons used for treating organic-loaded wastewater. Total global methane emissions from waste disposals and from wastewater lagoons are estimated to be 20–70 million tonnes per year, or on average 8 percent of total anthropogenic methane emissions.

CONTRIBUTION OF AGRICULTURE, FORESTRY, AND OTHER HUMAN ACTIVITIES TO GREENHOUSE GASES

The agriculture and forestry sector is an important source of greenhouse gases accounting for approximately 23 percent of total carbon equivalent greenhouse gas emissions from anthropogenic sources in the 1980s. These sources include rice production, ruminant animals, fertilizers, loss of soil organic matter, land conversion, biomass burning, and other non-energy activities.

Deforestation contributes between 0.4 and 2.8 billion tonnes of carbon (BTC), and biomass burning (forests, savanna, and shrub-fallow) between 20 and 80 million tonnes (MT) methane per year. The scientists who addressed the IPCC Tropical Forest Workshop, São Paulo, Brazil, January 1990 were reasonably certain that in 1980 emissions were between 1.0 and 2.0 billion tonnes of carbon (BTC), and in 1989 emissions were between 2.0 and 2.8 BTC.

Ruminant animals produce methane as part of their natural digestive process. Total methane emissions from domestic ruminant animals have been estimated to be between 65 and 100 million tonnes per year. In addition, animal wastes from anaerobic waste management systems are likely to yield on the order of 15 million tonnes globally.

Flooded rice fields produce methane due to microbial decay of organic matter. While uncertainty exists, they appear to account for between 25 and 170 million tonnes, or on average 20 percent of global methane emissions. Rice production is expected to increase from the current level of 458 million tonnes to over 750 million tonnes by the year 2020.

Loss of soil organic matter from agricultural soils is uncertain but could amount to up to 2 billion tonnes of carbon (BTC) per year.

Use of nitrogen fertilizers results in emissions of nitrous oxide equivalent to 0.01–2.2 million tonnes of nitrogen per year.

Biomass burning for land use conversion and the burning of agricultural wastes is estimated to account for over half of all biomass burned annually. These agriculture-related activities therefore contribute over 5–10 percent of total annual methane emissions, 3 to 8 percent of nitrous oxide emissions, 10–20 percent of carbon monoxide emissions, and 5–20 percent of NO_x emissions.

Landfill sites and wastewater treatment plants emit about 20–80 million tonnes of methane per year.

FUTURE GREENHOUSE GAS EMISSIONS

Future greenhouse gas emissions are difficult to predict because of uncertainties in estimating economic and population growth rates, and changes in forestry agriculture practices, and climate sensitivity. Scenarios of emissions, which must be used with caution, suggest that emissions are likely to grow well into the future without mitigating policy measures (see Executive Summary Table 4.1). These estimates suggest that CO_2 emissions from deforestation could range between 1.1 and 3.9 billion tonnes of carbon in 2020, that methane emissions from flooded rice will increase to about 150 million tonnes in 2025, and that methane emissions from managed livestock (including their wastes) will increase to about 185 million tonnes. Nitrous oxide emissions from use of nitrogen fertilizers will probably increase by up to about 3.5 million tonnes. Emissions from biomass burning are highly uncertain and have been assumed to remain constant at 55 million tonnes as a minimum.

Emissions of methane from landfill sites and wastewater treatment plants will probably increase to about 50–90 million tonnes per year by the year 2020.

POLICY OPTIONS, TECHNOLOGIES, AND PRACTICES TO REDUCE EMISSIONS

Currently available policies, technologies, and practices in forestry, agriculture, and waste disposal are likely to be only partially effective in reducing the predicted growth in emissions, unless they are coupled with emission reductions in the energy and industry sector. However, many practices and technologies are available today that, if utilized, could modify the rate of growth in emissions and that appear to make sense for economic and environmental reasons. Other options have been identified that require additional research and demonstration. Policies should address not only technical options but also instrumental (economic, regulatory, information, etc.) and institutional options in order to become effective. Although uncertainties about the rate and extent of climate change remain, it is recommended that all countries take steps to:

- adopt clear objectives for the conservation, reforestation, and/or sustainable development of forests in national development plans;
- amend national policies to minimize forest loss associated with public and private development

EXECUTIVE SUMMARY TABLE 4.1: Estimates and Projections of Annual Anthropogenic Emissions of Greenhouse Gases from Agriculture, Forestry, and Waste Management Activities

	1985			2020–2025		
	CO_2 (BTC)	CH_4[a] (MT-CH_4)	N_2O (MT-N)	CO_2 (BTC)	CH_4 (MT-CH_4)	N_2O (MT-N)
Land Use Changes[b] (Including Deforestation[c])	1.0–2.0	50–100	—	1.1–3.9	50–100	—
Biomass Burning[b]	3.9	20–80	0.2	—	—	—
Animal Systems	—	65–100	—	—	170–205	—
Rice Cultivation	—	25–170	—	—	100–210	—
Nitrogen Fertilizer	—	—	0.01–2.2	—	—	—
Loss of Soil Organic Matter	0–2	—	2.9–5.2	—	—	—
Waste Management	—	20–70	—	—	50–90	—
Total Annual Anthropogenic Emissions from All Sources (Including Energy Use)	6	540	12	12	760	16

[a] CH_4 can be expressed as tonnes carbon by multiplying the CH_4 estimate by 0.75.

[b] Land use changes and biomass burning estimates overlap and are not additive.

[c] A recent preliminary report on tropical deforestation (Myers, 1989) estimates emissions from deforestation to be 2.0–2.8 BTC per year for 1989, with a mean working figure of 2.4 BTC.

Sources: IPCC Working Group I Final Report, Summer 1990; IPCC AFOS Tropical Forestry Workshop, São Paulo, 1990; Andreae, 1990; IPCC-AFOS Agriculture Workshop, Washington, D.C., 1990.

projects (e.g., roads, dams, resettlement projects, mining, logging);

- adopt forest management solutions integrated across sectors to policies on environment, agriculture, transportation, energy, economics, poverty, and landlessness;
- implement policies to promote increasing productivity in sustainable agriculture and to protect natural resources; and
- improve public awareness of all these points through education programmes.

Policy options need not be implemented in sequence, i.e., policies should be implemented as it becomes apparent that they meet a number of national needs. In addition, policies associated with production, processing, storage, transportation, and marketing need to be examined to derive the optimum effectiveness from research, technological developments, and land use practices. To promote sustainable agriculture and forestry, analyses are needed of economic incentives, taxes, pricing and trade barriers, cultural practices, technology transfer measures, education and information programmes, and international cooperation and financial assistance measures.

Criteria for the Selection of Policy Options

It is important that these options be pursued without undue economic disruption. Policies should also:

- be of widespread applicability;
- be compatible with the social and economic life of communities dependent on agriculture and forestry;
- be equitable in the distribution of the burdens of action between developed and developing countries, taking into account the special situation of the latter;
- result in the spread of knowledge, management skills, and technologies;
- result in net environmental gain; and
- take account of the fact that emissions in this sector largely comprise many small sources or diffuse sources from large areas.

NEAR-TERM OPTIONS

The opportunities for reducing greenhouse gas emissions and enhancing carbon sinks in the near term include the following:

Forestry

- Develop and implement policies that will reduce current deforestation and forest degradation to reduce greenhouse gas emissions and enhance forest areas as carbon sinks.
- Improve efficiency of use of fuelwood.
- Introduce sustainable harvesting and natural forest management methods to reduce tree damage.
- Partially replace fossil energy sources by sustainably managed sources of biomass which would reduce net emissions of additional CO_2.
- Increase efforts to replace high energy input materials with wood, and encourage further recycling of forest products in order to provide for long-term storage of carbon.
- Strengthen the use of remote sensing in forest management and in the determination of forest removal and emission patterns, by developing and coordinating data collection and analyses among relevant institutions.
- Determine the feasibility of implementing the Noordwijk Declaration aim of achieving net global forest growth of 12 million ha per year, through conservation of existing forests and aggressive afforestation, and develop appropriate national strategies.
- Perform analyses for and begin to implement large-scale national forestation and forest protection plans.
- Identify and eliminate inappropriate economic incentives and subsidies in forestry and non-forest sectors that contribute to forest loss.
- Develop enhanced regeneration methods for boreal forests in order to cope with change in the climate.
- Ensure the health of existing forests, in particular by reducing air pollution, e.g., acid deposition, tropospheric ozone, SO_2, NO_x, NH_3, VOCs, etc., by adopting appropriate policies to reduce site-specific and regional pollution problems.
- Use available surplus agricultural land for forestry as appropriate.
- Fully integrate the requirements of forest conservation and sustainable management in all relevant sections of national development planning and policy.
- Evaluate the implications of population growth and distribution for the achievement of national forestry measures and take appropriate action.

Agriculture

- Reduce biomass burning through fire control, education and management programmes, as well as the introduction of the use of appropriate alternative agricultural practices.
- Modify agricultural systems dependent on the removal of biomass by burning to provide opportunities for increasing soil organic matter and reduction of greenhouse gas emissions.
- Reduce methane emissions through management of livestock wastes, expansion of supplemental feeding practices for livestock and increased use of production and growth-enhancing agents with appropriate safeguards for human health and taking into account legitimate consumer concerns.
- Reduce nitrous oxide emissions by using improved fertilizer formulations and application technologies, and through judicious use of animal manure.
- Introduce where appropriate minimum- or no-till systems that are recommended for those countries currently using tillage as part of the annual cropping sequence, to yield additional benefits such as direct energy savings, improved soil tilth, and increased soil organic matter.
- Use areas marginally suitable for annual cropping systems for perennial cover crops for fodder or pastoral land uses, or forests if soils are suitable. This would increase carbon uptake, both in the vegetation and soil, and would yield other benefits such as reduced soil erosion, improved water infiltration and quality, and delayed streamflow.

Waste Management

- Consider using landfill gas collection systems and flaring to reduce methane emissions in developed countries where practical.

- Use biogas systems to treat wastewater in developing countries in order to reduce methane emissions and provide inexpensive sources of energy.
- Promote maximum recycling of wastes.

Longer-Term Options

Several opportunities for reducing greenhouse gas emissions and enhancing carbon sinks have been identified for the longer term. In general, these opportunities must be developed, demonstrated, and assessed in terms of greenhouse gas reductions and the full range of potential costs and benefits. These alternatives must maintain or enhance the productivity of agriculture and forestry systems. This will require substantial research efforts focused on better understanding of the processes by which these gases are emitted, further investigation of promising options, and better field measurement devices.

Forestry

- Develop and implement standardized methods of forest inventory and bio-monitoring to facilitate global forest management and to make production ecology studies and cost/benefit analyses comparable across forest areas.
- Increase wood production and forest productivity by silvicultural measures and genetically improved trees, thus helping to increase the forest carbon sink, to meet increasing demand for wood as well as to support replacement of fossil fuels and other materials by wood and to avoid inappropriate land use conversion.
- Incorporate forest protection strategies for fire, insects, and diseases into future management and planning under various climate change scenarios.
- Develop and implement silvicultural adjustment and stress management strategies to maintain existing forests.
- Develop and implement environmentally sound management practices for peatlands that restrict the release of carbon, especially as methane.
- Make use of the specific opportunities of intensively managed temperate forests to mitigate the greenhouse effect by expanding their biomass.

Agriculture

- A comprehensive approach including management of water regimes, development of new cultivars, efficient use of fertilizers, and other management practices could lead to a 10–30 percent reduction in methane emissions from flooded rice cultivation, although substantial research is necessary to develop and demonstrate these practices. A 10 percent reduction in emissions from rice systems may contribute about 15–20 percent of the total reduction required to stabilize atmospheric concentrations of methane.
- Through a number of technologies it appears that methane emissions from livestock systems may be reduced by up to 25–75 percent per unit of product in dairy and meat production. The net effect of such improvements depends upon the extent to which such methods can be applied to domestic ruminant populations, which will vary greatly from country to country. However, each 5 percent reduction from this source could contribute 6–8 percent of the reduction necessary to stabilize methane in the atmosphere.
- Fertilizer-derived emissions of nitrous oxide potentially can be reduced (although to what extent is uncertain) through changes in practices such as using controlled-release nitrogen, improving fertilizer-use efficiency, and adopting appropriate alternative agricultural systems.
- Trace gas emissions from biomass burning, land conversion, and cropping systems may be reduced through widespread adoption of sustainable agricultural practices, optimizing use of fertilizer and organic amendments, and improved pasture management and grazing systems. These gains may be offset by pressures of increasing population and increased demand for food and fiber production.

General Issues Affecting the Agriculture, Forestry, and Waste Management Sectors

Emissions from these sectors are intimately related to the ability of countries to provide for national and global food security and raw materials for export. Policies for emission control and sink enhancement therefore may affect the economic basis of some countries, especially developing countries. Efforts to prevent deforestation and to promote afforestation will have multiple impacts that in many cases may enhance the abilities of indigenous agricultural communities to feed themselves and to earn a living from local surplus. Flexibility should be provided to governments to develop least-cost implementation strategies, and countries should pursue those options that increase productivity, make economic sense, are environmentally sound, and are beneficial for other reasons. Agriculture, forestry, and waste treatment sources of greenhouse gas emissions consist of very large numbers of small sources and/or of diffuse sources from large land areas, and as such represent a major challenge.

Controls on existing sources of pollution that may affect agricultural and forestry lands are an important component in reducing emissions and protecting sinks. Measures to prevent land degradation, hydrological problems, and loss of biodiversity and to improve productivity will generally complement efforts in this sector. Furthermore, analysis is needed about the costs and benefits of individual policy measures.

It is desirable to consider a range of measures in the context of a comprehensive response strategy. Currently available options in the agriculture and forestry sectors are likely to be only partially effective unless coupled with action to reduce emissions from the energy and industry sector. There is an urgent need to improve all relevant data, especially on deforestation rates and on the socio-economic factors that lead to the use of deleterious practices in agriculture and forestry. In order to achieve the full potential of identified measures, research is needed into the routes by which new technologies can be introduced while preserving and enhancing social and economic development.

In the past, the agriculture and forestry sector has proved efficient at introducing new methods of production, not always with beneficial ecological consequences. The pace of technological development (even in the absence of global warming) is likely to remain high in this sector for the foreseeable future. This may afford new opportunities for emission reduction and sink enhancement, provided efficient transfer of knowledge, advice, and technology occurs.

INTERNATIONAL OPTIONS

A broad range of institutional issues must be addressed in order to ensure that the objectives of increased global food production and reduced greenhouse gas emissions can be met in the future. Among the options that governments, international organizations and intergovernmental bodies such as IPCC should consider are the following:

- A series of agricultural workshops and symposia to assess new information on agricultural production and emission forecasts, exchange information on the effectiveness of new technologies and management practices, and evaluate the potential impact of agricultural policies. These meetings should address the institutional and economic issues particular to the major agricultural sources of emissions, such as biomass burning, temperate agricultural practices, livestock emissions, and emissions from rice cultivation.

- Guidelines for future research by FAO, CGIAR (Consultative Group on International Agricultural Research), IUFRO (International Union of Forestry Research Organisations), and others to address the need to investigate impacts of climate change and options for reducing emissions.

- Strengthen, support and extend the Tropical Forestry Action Plan process to all countries with tropical forests, and expand support for immediate implementation of completed plans.

- Strengthen the role of ITTO to develop international guidelines to encourage:
  a) sustainable forest management techniques, including national legislation requiring management of forest for sustained wood production;
  b) an assessment of incentives for sustainable forest management including feasibility of labeling.

- Strengthen the role of development banks, IMF, FAO, UNEP, and other multilateral or bilateral international organizations in helping developing countries achieve conservation and sustainable development of forests and agriculture by:

a) requiring analyses of climate change implications, potential greenhouse gas emissions, and response programmes in their review of project proposals;
b) expanding greatly aid and investment flows to both sectors;
c) expanding debt relief via renegotiation of debt, and debt for conservation exchanges; and
d) linking structural adjustment measures to alleviation of climatic impacts and reduction of gas emissions.

Development of a World Forest Conservation Protocol

The following declaration was agreed upon in the workshop on tropical forests in São Paulo in January 1990:

> Consideration of forestry issues, and of tropical forestry issues in particular, must not distract attention from the central issue of global climate change and the emission of greenhouse gases attributable to the burning of fossil fuels by developed countries. No agreement on forests and global climate change will be reached without commitments by developed countries on greenhouse gas emissions. The groups recognized that the conservation of tropical forests is of crucial importance for global climatic stability (particularly having regard to the important contribution of tropical forest destruction to global warming, carbon dioxide, methane, and other trace gases), but of more crucial importance for national economic and social development, for the conservation of biodiversity, and for local and regional climatic and environmental reasons. The Workshop recommended that the IPCC support the development of a forestry protocol in the context of a climate convention process that also addressed energy supply and use. The Workshop concluded that the specific elements of such a protocol are a matter for international negotiations. These elements may include: fundamental research, tropical forest planning, measures to use, protect, and reforest, international trade, financial assistance, and the advantages and disadvantages of national and international targets. The objective should be to present more concrete proposals on the occasion of the UN Conference on Environment and Development, to be held in 1992.

In light of the above, it is recommended that a World Forest Conservation Protocol, covering temperate, boreal, and tropical forests, be developed in the context of a climate convention process that also addresses energy supply and use, as noted by the January 1990, IPCC/RSWG Tropical Forest Workshop in São Paulo, Brazil, and that in accordance with UNGA Resolution 44/207, operative paragraph 10, a meeting of interested countries from both the developed and developing world and of appropriate international agencies be held to identify possible key elements of such protocols and practical means of implementing them. Such a meeting should also develop a framework and methodology for analyzing the feasibility of the Noordwijk remit, including alternative targets as well as the full range of costs and benefits.

All countries should make a contribution to the solution of the global warming problem. The São Paulo Workshop stated:

> Although forests can assist in mitigating the effects of atmospheric carbon build-up, the problem is essentially a fossil fuel one and must be addressed as such. In this way, and as a general principle, the final report of the present IPCC Workshop on Tropical Forests, while putting tropical forests in the overall context of global warming, should make it clear that the burden of response options is not to be placed on developing countries and thus should state clearly that all countries should make a contribution to the solution of the global warming problem. The temperate forest dieback (caused by acid rain), as analogous to tropical deforestation (caused by tropical people's attempts to satisfy basic human needs), could be specifically mentioned in such a context.

It should, however, be noted that recent findings indicate that forests may be adversely affected throughout the world by a variety of causes, only one of which is acid deposition.

The São Paulo Workshop further noted:

> Forests cannot be considered in isolation, and solutions must be based on an integrated approach which links forestry to other policies, such as those concerned with poverty and landlessness. The forest crisis is rooted in the agricultural sector and in people's needs for employment and income. Deforestation will be stopped only when the natural forest is economically more valuable than alternative uses for the same land.

4.1 INTRODUCTION

This report examines the roles of agriculture, forestry, and human activities other than energy production and industry as sources of greenhouse gases, and possible measures for reducing their emission into the atmosphere.

Working Group I of IPCC suggests in its report that the global average temperature will rise within the next 80 years by about 2.4–5.1 degrees C above pre-industrial, with a best estimate of 3.5 degrees C. Predictions of concomitant changes in precipitation and wind patterns are much less certain. Little information is currently available on the rate of change, transient conditions, and changes in the occurrence of extreme events such as storms and forest fires.

Agriculture- and forestry-related activities contribute to the emission of greenhouse gases, notably of carbon dioxide, methane, and nitrous oxide. These sectors account for approximately 23 percent of greenhouse gases from anthropogenic sources in the 1980s. These sources include rice production, ruminant animals, fertilizers, land conversion, biomass burning, and other non-energy activities.

Deforestation contributes between 0.4 to 2.8 billion tonnes of carbon (BTC), and biomass burning (forests, savanna, and shrub-fallow) between 40 and 75 million tonnes (MT) methane per year. The scientists who addressed the IPCC Tropical Forest Workshop in São Paulo were reasonably certain that in 1980 emissions were between 1.0 and 2.0 BTC and that in 1989 emissions were between 2.0 and 2.8 BTC.

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Loss of soil organic matter from agricultural soils is uncertain but could amount to up to 2 billion tonnes of carbon (BTC) per year.

Biomass burning for land use conversion and the burning of agricultural wastes is estimated to account for over half of all biomass burned annually. These agriculture-related activities therefore contribute over 5–10 percent of total annual methane emissions, 3–8 percent of nitrous oxide emissions, 10–20 percent of carbon monoxide emissions, and 5–20 percent of NO_x emissions.

Landfill sites and wastewater treatment plants emit about 30–70 million tonnes of methane per year.

Future greenhouse gas emissions are difficult to predict because of uncertainties in estimating economic and population growth rates and changes in forestry and agriculture practices. Scenarios of emissions, which must be used with caution, suggest that emissions are likely to grow well into the future without policy measures (see Table 4.1). These estimates suggest that CO_2 emissions from deforestation could range between 1.1 and 3.9 billion tonnes of carbon in 2020, that methane emissions from flooded rice will increase to about 150 million tonnes in 2025, and that methane emissions from managed livestock (including their wastes) will increase to about 185 million tonnes. Nitrous oxide emissions from use of nitrogen fertilizers will

TABLE 4.1: Estimates and Projections of Annual Anthropogenic Emissions of Greenhouse Gases from Agriculture, Forestry, and Waste Management Activities

	1985			2020–2025		
	CO_2 (BTC)	CH_4[a] ($MT\text{-}CH_4$)	N_2O (MT-N)	CO_2 (BTC)	CH_4 ($MT\text{-}CH_4$)	N_2O (MT-N)
Land Use Changes[b] (Including Deforestation[c])	1.0–2.0	50–100	—	1.1–3.9	50–100	
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Nitrogen Fertilizer	—	—	0.01–2.2	—	—	—
Loss of Soil Organic Matter	0–2	—	2.9–5.2	—	—	—
Waste Management	—	20–70	—	—	50–90	—
Total Annual Anthropogenic Emissions from All Sources (Including Energy Use)	6	540	12	12	760	16

[a] CH_4 can be expressed as tonnes carbon by multiplying the CH_4 estimate by 0.75.

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probably increase to about 3.5 million tonnes. Emissions from biomass burning are highly uncertain and have been assumed to remain constant at 55 million tonnes, as a minimum.

Emissions of methane from landfill sites and wastewater treatment plants will probably increase to about 50–90 million tonnes per year by the year 2020.

Agriculture and forestry may also contribute to gases such as NO_x, ozone, and carbon monoxide, which contribute indirectly to the greenhouse effect. While significant, these sectors are of course not the only sources and also provide sinks for carbon dioxide. As a consequence, any consideration of measures and policy options to control emissions from these sectors must take account of the overall effects of greenhouse gases.

The interactions between climate change and agriculture and forestry management complicate precise evaluation.

- Climate change in itself will affect forests and agriculture. In an altered climate, change will tend to increase stress on the biosphere in a variety of ways. For instance, seasonal rainfall patterns might change. Similarly, extreme weather events could occur more frequently. Further, the risk of forest fires and diseases might increase.
- Altered forest and agriculture patterns will in turn affect the climate. The areas where the cover changes from forest to agriculture will reflect light from the sun differently, and this altered albedo, by changing the radiation balance, might also change climate. Similarly, climate-related changes in needs for irrigation will affect hydrological cycles, including cloud formation, which could significantly affect climate.
- Anthropogenic emissions that affect climate might also directly affect forests and agriculture. In the temperate zone, where most of the tropospheric ozone precursors are emitted, ozone, which contributes to the greenhouse effect, can cause direct damage to vegetation.

While these complex mechanisms need to be clarified, the need for further research is no excuse for delaying action.

Counter-measures may pose challenges for food and fiber security. Options to reduce greenhouse gas emissions should be balanced with the growing demand for food and fiber and other material goals. The approach for developing options should be to maintain and increase agricultural production in a sustainable manner while reducing greenhouse gas emissions.

This report also addresses the role and control of organic matter decomposition in wastes and wastewaters, which can, under anaerobic conditions, contribute significantly to methane emissions (approximately 15 percent of global anthropogenic release).

AFOS organized a series of workshops on:

- Boreal Forests (October 9–11, 1989 in Finland)
- Temperate Forests (October 30 to November 1, 1989 in the Federal Republic of Germany)
- Agriculture (December 12–14, 1989, in the United States)
- Tropical Forests (January 9–11, 1990, in Brazil)

to assess the significance of emissions from these sectors and possible options for their control. These workshops were attended by representatives from all concerned regions. The following sections on forestry and agriculture are based on the reports of these workshops. The section on methane from landfill sites and wastewater treatment plants is based on a report prepared by one of the participating countries.

4.2 FOREST RESPONSE STRATEGIES

The total area of forests (excluding other wooded lands) at present amounts to approximately 4 billion ha, roughly half of it tropical forests, the other half temperate or boreal forests, one third and two thirds respectively. During the course of human history, roughly 2 billion ha have been lost due to various human activities.

The amount of carbon presently stored in forests is equivalent to the amount in the atmosphere—namely, approximately 700 billion tonnes carbon. This means that 1 ha of forest contains on a global average between 100 and 200 tonnes of carbon, while afforested areas fix on average 5–10 tonnes carbon per ha per year.

Land uses involving conversion of forest through burning of biomass or felling contribute about 9 percent of greenhouse gas emissions, and about 15–30 percent of anthropogenic CO_2 emissions.

The Noordwijk Declaration on Atmospheric Pollution and Climate Change states in point 21 that,

> The Conference . . .
>
> - agrees to pursue a global balance between deforestation on the one hand and sound forest management and afforestation on the other. A world net forest growth of 12 million hectares a year in the beginning of next century should be considered as provisional aim.
> - requests the IPCC to consider the feasibility of achieving this aim. . . .

The outcomes of the forestry workshops clearly demonstrate the necessity both to conserve forest resources and to implement measures to increase forest biomass at the same time. Existing forests serve a multitude of functions vital for mankind in addition to providing wood as a renewable resource. However, it is important to recognize that reforestation of areas where forests have previously been destroyed does not immediately fulfill all the functions of an intact forest. In addition to the dangers of loss of biodiversity and soil erosion that arise with deforestation, deforestation releases around 100 tonnes of carbon per hectare both immediately, through biomass burning, and in the longer term, through decomposition of biomass and humus. Newly afforested areas fix on average around 5–10 tonnes of carbon per ha per year. Thus, it takes decades to fix again the carbon released by deforestation. Conservation of forests is therefore of paramount importance.

At present, around 1 billion tonnes of carbon are released into the atmosphere annually by forest destruction, primarily through anthropogenic activities as a consequence of growing population and rising demand for food and fiber. The total release of carbon by anthropogenic activities is of the order of 7–8 billion tonnes, of which about 6 billion tonnes are released due to burning fossil fuels.

Reforestation of deforested areas is a valid counter-measure. Currently, only one million hectares per year are being afforested. In addition to the area needed to balance deforestation (according to estimates for 1980–85 about 11–12 million ha per year), it is estimated that in 20–50 years, very roughly, up to 200 million hectares might be planted, which would require an average rate of 4–10 million ha per year. Such an area could store up to about 20 percent of present carbon dioxide emissions for a limited time. The area that could be afforested, however, depends on several other factors. Providing food or housing for a growing world population will also require areas that cannot then be afforested; soil degradation, possibly amplified by climate change, will reduce the area that could usefully be afforested; and the time needed to implement these measures might in practice be longer than 50 years. These points make it difficult to attain a yearly net forest growth goal of 12 million hectares per year as set by the Noordwijk Declaration.

Afforestation costs are highly dependent on the specific area, the tree species and local wages. A rough global estimate ranges from U.S. $200 to $2,000 per hectare. Detailed studies are needed to obtain more reliable figures; costs and carbon dioxide reduction figures obtainable by afforestation should also be compared with other measures possible in industrialized countries—for example, energy sector counter-measures. However, this in no way limits the usefulness of conservation measures. The amount of afforestation required to balance total anthropogenic carbon dioxide emissions—7–8 billion tonnes—would be about 1 billion ha, or an area the size of Europe from the Atlantic to the Urals. Afforestation on such scale is impracticable, so that forestry measures can play only a minor but significant contributory role in reducing the buildup of greenhouse gases. It might be realistic to achieve a 10–15 percent reduction of such emissions. This role is small in comparison to the potential emissions of CO_2 implied by a continuing (and even increasing) global reliance on fossil fuels.

Forests may be able to adapt to a rate of temperature change of around 1 degree C in 100 years, but the more rapid changes predicted are likely to have deleterious effects, especially in combination with additional stress factors such as air pollution.

The response of forest ecosystems to temperature change depends, however, on a great number of other parameters (e.g., precipitation, extreme climates) on which no information is available at the moment. Shifts may occur in the ranges and species composition of forest communities, together with crisis-type disturbances in development and changes in biodiversity and genetic diversity of individual species.

Policies and Measures

It must be accepted from the outset, however, that the ultimate contribution of forestry can only be to facilitate a transition from our reliance on fossil fuels over the next 50–75 years. Since global warming could affect the distribution, productivity, and health of forests, it is necessary that measures to control greenhouse emissions should be taken both within and outside this sector. Almost half of the man-made increase in atmospheric greenhouse gas levels is caused by the burning of fossil energy sources. Conservation of fossil fuels and the use of alternative energy sources including the use of renewable energy sources is therefore essential, as well as measures to reduce emissions from fossil fuel sources. Changes in energy policies must take account of the environmental consequences of particular energy options.

Forestry policies can be identified which could contribute to a global warming response strategy. In this context, reducing current deforestation and forest degradation should be a first priority. It is also vital to make a contribution to the reduction of the man-made increase in the greenhouse effect by making greater use of wood. The partial replacement of fossil energy sources by wood will reduce the emission of additional CO_2. Wood in competition with building material and other material whose production requires many times more energy contributes to energy savings and to maintaining carbon sinks. Wood production from genetically improved trees and intensively managed forest can replace fossil fuel carbon with the aid of silvicultural and breeding measures. As these measures can be carried out on substantial areas of existing forested land, a significant potential will be available in the long run.

Monitoring and Research

There is a need to strengthen bio-monitoring of forests to complement the atmospheric monitoring already under way. Standardized methods of forestry inventory are required to provide the data necessary to manage forests globally. This would also mean that studies of production ecology and cost/benefit analyses would be comparable across forest areas. Major gaps in knowledge include soil properties, primary nutrient cycling, and decomposition in the forest floor. Provided that the impacts of other environmental factors on tree growth are not too great and do not counteract the direct effects of CO_2, it is theoretically possible that increased atmospheric CO_2 concentrations might increase yield. Appropriate species and provenances would be required and suitable silvicultural measures would have to be adopted to take maximum advantage of such a situation.

Forest Protection

Fire protection strategies based on fire hazard information should be developed and incorporated into future management and planning under climatic change scenarios.

Better forest pest protection strategies should also be developed. The activity, abundance, and distribution of most forest insect and disease species, especially in temperate and boreal areas, are expected to increase with increasing temperatures.

Forest Management

Forest and woodland biomass can be managed by maintaining yields of existing forests and by increasing the productivity of native, exotic, and genetically improved species.

Forest managers and researchers have believed that forest renewal, productivity, health, and diversity would be assured by prudent silvicultural practices. Much of our knowledge and procedures for strategic planning and management have been based on empirical data such as growth and yield models, and the validity of these may be suspect under a change of climate. Therefore, a review of current silvicultural practices and data is required.

Land availability and the difficulty of securing forests against unsustainable exploitation are important constraints. However, possibilities exist for enhancing land productivity through reforestation and improved forest management. These constraints can be overcome, provided that local communities share adequately in the benefits from forest conservation and reforestation. These include provision of employment, access to produce from the forest, and benefits associated with effective land-use management of adjacent agricultural areas that include appropriate agroforestry development.

Forestry and Agriculture

Research is needed into the interactions of forestry and agriculture in terms of biological, agronomic, and economic aspects. In particular, the possibilities of encouraging farm woodland and agroforestry activities need further consideration. Increasing experience with silvi-pastoral and silvi-arable systems is becoming available and may have useful environmental and economic benefits. Particularly in temperate areas, many countries are now looking to farm forestry as a means of controlling agricultural surpluses. This trend should also be encouraged because of its potential effects on greenhouse gas emissions.

End Uses and Biomass Conversion

The need and demand for raw materials from forests has increased globally, especially in the pulp and paper industry. If timber could be utilized more effectively and a larger percentage of timber products recycled, less wood would need to be cut from forests without resulting in a decrease in industrial production. This would leave more standing biomass in the forest over a longer time to sequester carbon dioxide. Extension of rotation periods may be possible in managed forests. An alternative would be to grow trees for shorter rotations than at present, as trees would then be exposed for a shorter time to stressful and changing conditions, and the carbon could be stored in the end product. Materials such as concrete, steel, and aluminum could often be replaced by wood, which would have the added advantage of saving on the energy required in the production of these materials and on the consequent carbon emissions.

Climate stress and damage caused by insects and diseases may produce wood with different properties than the materials now used. How to harvest and use such wood needs to be investigated. Carbon dioxide emissions from electrical energy production are lowest with wood biomass, due to cycling and refixation of carbon. Using a sustainably managed source of biomass, such as intensive, short-rotation fuelwood plantations, biomass energy could produce net reductions in carbon dioxide emissions. However, the use of forest biomass for energy should not be promoted to the detriment of forest ecosystems.

Use of logging and milling residues (bark, timber residues) should also be considered—for instance, in energy production. In many countries, wood is still utilized in large quantities for energy purposes, and indeed, shortage of wood for firewood is a problem in many tropical countries. One aim could be to maintain or even increase the usage of wood for energy through the development of technology under a sustainable management policy.

Sections 4.2.1–4.2.3 address the issues particular to boreal, temperate, and tropical forests.

4.2.1 SPECIAL ISSUES ON BOREAL FORESTS

4.2.1.1 *Introduction*

The boreal forest is one of the world's major vegetation regions, occupying 1,200 million square ha. Coniferous species dominate the zone that encircles the globe through northern Eurasia and North America from about 45N to 75N. The boreal forest in North America and eastern Asia contains many species not found in the Euro-Siberian region. The majority of its soils are covered by ericaceous plants, lichens, and moss species in an understory that is usually cold, and permafrost is common. The dependence of national economies and indigenous people on forestry in the boreal region is strong. Even with new technology and urbanization, forests and forestry still play major roles in peoples' lives, by providing subsistence or recreation. The cultures and economies of forest peoples, such as the Athabaska Indians and Eskimo of Alaska or Nordic Laplanders, are intricately adapted to the natural environment and depend upon it for self-perpetuation.

4.2.1.2 *Carbon Sinks of the Boreal Region*

An estimated 25 percent of the global soil carbon is contained in boreal forest soils, and significant amounts of this carbon will be lost if the lands overlying these soils are converted to other uses. In addition, drainage of boreal muskegs and peat bogs would release more nitrous oxides and carbon dioxide as water tables drop, while maintaining high water tables in these systems would release more methane.

The boreal forests may be divided into (1) managed, (2) intermediate, and (3) non-managed forests. Nordic countries within the boreal zone (Finland, Norway, and Sweden) fit into the first category. The total boreal forest area of these countries is about 50 million ha, and annual removals of industrial roundwood and fuelwood are approximately 100 million cubic meters.

In Canada approximately 55 percent of its boreal forest (210 million ha) has been classified as productive forest. However, only a small part of the productive forest is under active forest management; thus it is classed as an intermediate forest. Total removals of industrial roundwood and fuelwood, during 1986, were approximately 115 million cubic meters. Within the boreal forest region, the highest proportion of non-managed forests are in Alaska (USA) and Yakutia (USSR). According to figures, Alaska, for instance, has 9 million ha of commercial forest land, which is equivalent to less than 10 percent of the total forest area. In Yakutia, the total forest area is approximately 150 million ha. Recent information from Soviet sources suggests that the approximate total boreal forest area in the Soviet Union is 600 million ha.

4.2.1.3 *Consequences of Climate Change on Emissions*

The prevailing climate determines the structure and function of the boreal forest ecosystem, including components of the carbon balance, productivity, physiology, insects, diseases, and fire. Current predictions suggest that in the boreal zone the change in temperature will be relatively low in Norway, because of its maritime climate, but high in northwestern continental Canada. However, the direct and combined effects of CO_2 enrichment and temperature change on boreal tree species are not fully understood. Nutrient cycling, for example, will be accelerated by an increase in temperature and could increase productivity if accompanied by appropriate moisture. Results obtained in a study carried out by Environment Canada (1988) using growth indices, indicated that there would be a northward shift of major forest ecosystems by up to several hundred kilometers. Similar effects may be expected in other countries with boreal forests.

The incidence of forest fire is strongly connected to climatic events. Fire has an important role in the carbon cycle because it returns carbon to the atmosphere faster than any other process. In Canada the occurrence of wildfires has increased dramatically over the last ten years. During 1989, over 6 million hectares of forest land were consumed by fire. On the basis of the data from previous years the ten-year average has been about 2 million hectares, twice that being burned two decades ago. In addition to the above-ground biomass, a massive expanse of peatlands and permafrost in northern latitudes contains large reserves of carbon. According to the latest estimates, the boreal and arctic peatlands contain about 200 billion tonnes of carbon (Sjors 1981, Ahlholm and Silvold 1990). The warming of these areas will lead to unpredictable emissions of carbon in the form of methane and carbon dioxide.

4.2.1.4 *Possibilities to Refix Carbon Dioxide: A Case Study*

A case study of Finland prepared for the IPCC shows the effects of forest management strategies on the carbon storage of existing forests. It shows that in intensively managed commercial forests it is possible to affect considerably the carbon storage in forests through forest management strategies.

In the case study the time horizon is fifty years, from 1989 to 2039. It is assumed that sequestration of fossil fuel emissions during this period could help offset fossil fuels used during a transition to alternative sources of fuel. It is assumed in all the calculated alternatives that forests will continue to be utilized economically. The production of stemwood during the simulation period was not less than that presently recommended by forest management policies. The case study used the forest simulation model YSI, developed by Dr. Timo Pukkala, University of Joensuu, Finland. A forest management planning model based on the YSI simulation model was developed and it required extensive physical and biological data from the forest. The basic data for the calculations were taken from Finland's national forest inventory (1977–84).

In Finland's forests, the carbon content of the stemwood is about 320 million tonnes with a carbon content of the total above-ground tree biomass of about 590 million tonnes. Under a no-change scenario, about 270 million tonnes more carbon could be stored in above-ground biomass by selecting the appropriate forest management method supported by the model.

This increment equals the carbon emissions from the use of fuel oils in Finland during the next thirty-nine years, if the annual C-emissions remain at the 1989 level. If the climate warms up by 2 degrees C according to the example and assuming that the trees are capable of adapting to the new equilibrium, 470 million tonnes more of carbon can be stored in forests by changing management methods. This would equal the total use of fuel oils in Finland during the next 67 years. There are alternative strategies for forest management, even in already intensively managed forests, which can considerably increase the mean volume and the carbon storage of existing forests with little change in economic incomes or cutting amount. The net incomes in the calculation example will decrease due to delayed harvestings by less than 20 percent when discounted at 4 percent interest (costs and incomes are calculated with present prices). Beneficial strategies for carbon management could also be found using shorter rotations and increased growth. This case study demonstrates that it is possible to increase carbon storage by changing forest management strategies. The study suggests that forest management strategies are important response strategies to cope with the predicted climate change. It should be pointed out that this study offers the best-case scenario.

4.2.1.5 *Measures and Policy Options*

Forests may be considered as major indicators of the environmental and economic health of boreal forest countries.

4.2.1.5.1 Forest Protection

Protection activities related to fire, insects, and diseases in the boreal forests will have to be intensified to compensate for the changes in species composition due to northward migration of insects, and diseases need to be investigated to ensure timely action in maintaining forest health.

4.2.1.5.2 Forest Management

Results obtained from genetic trials in different countries have indicated that northern seed lots transferred southward have survived fairly well; but poorer than local trees in warmer climate conditions. This could be directly related to adaptation to longer days in more northern regions. There is considerable debate on whether forest land should be regenerated artificially or naturally. The approaches to this issue depend on whether one deals with managed or unmanaged forests and is related to economic questions. Recently, in Nordic countries, where artificial regeneration has been widely used, there have been extensive planting stock losses. Given these losses, artificial regeneration must be improved to ensure that native species can survive in a rapidly changing climate. While our present silvicultural practices have favored monocultures, growing conditions could change and mixed stands may be favored over the monocultures. It has been shown by Mielikainen (1985) that mixed stands could be economically valuable in Finland.

These areas will also serve as carbon reservoirs along with other large-scale reforestation projects. It should be noted that the market value of the forests varies from country to country and changes according to the end use of forest products. Within the boreal region lie extensive areas of peatlands. In Finland, 45 percent of the total forest land is wetland, of which about 50 percent has been drained. In addition, most boreal regions have discontinuous or continuous areas of permafrost and constitute a large source of carbon. In these areas, management practices should be implemented that restrict the release of carbon, especially methane, which is 16 times more effective as a greenhouse gas than carbon dioxide. It should be noted that forestry practices change the relation of anaerobic to aerobic conditions in soils that regulate the proportions of methane and carbon dioxide emissions.

4.2.1.5.3 End Uses and Biomass Conversion

During the ten-year period 1976–86, the demand for raw forest materials has increased globally, especially in North America. To meet the continuous demand for these products, the needs of the pulp and paper industry will have to be reflected in future forest resource management scenarios. Some of that demand will be filled through recycling of forest products. In the boreal forest the use of a sustainable managed source of biomass, such as an intensive short rotation fuelwood plantation, biomass energy can produce net reductions in CO_2. In addition, using logging residues (bark, timber residues) and black liquor from forest industrial activities should be considered in energy production.

4.2.2 SPECIAL ISSUES ON TEMPERATE FORESTS

This section deals with temperate forests located in Europe (including the Mediterranean area and excluding Northern Scandinavia), the Middle and Near East, Central and East Asia, Australasia, most of North America, Chile, and Argentina. The total area of temperate zone closed forests is estimated to be about 600 million ha or 17 percent of the Earth's total closed forest area (3,600 million ha). This section focuses on how and to what extent temperate forest destruction contributes to the man-made increase in the greenhouse effect and how climate change may influence such forest ecosystems, and considers measures to protect the forests and to increase their capacity to absorb CO_2 from the atmosphere.

4.2.2.1 *Greenhouse Gas Emissions from Temperate Forests*

A natural or sustainably managed temperate forest is neither a source nor a sink of CO_2. At present, over large regions the carbon balance is achieved by forest growth in one area being offset by loss of biomass in another (e.g., by harvesting, wildfires, severe storms, etc.). Thus, as long as their total area is relatively stable, their contribution to emissions is negligible.

4.2.2.2 *Global Warming: Impacts and Effects on Temperate Forests*

Climate changes in the post-glacial period have significantly altered the composition of forest communities in temperate zones. Tree species and forest types were displaced or changed composition. Forest communities have been able to adapt within certain limits and rates of climate changes, with some communities adapting intact and others undergoing changes in species composition. However, the rate of climate change now predicted may exceed these limits by far.

In temperate zones, human activities have had multiple impact on the natural range and composition of forests. During the course of human history, cumulative forest losses amount to about 2 billion ha mostly in temperate zones (equivalent to the present total tropical forest area). Some regions have become poor in forest resources. The remaining forests are thus all the more important, as they continue to fulfill multiple functions (e.g., watershed protection, habitats, timber production, etc.) and maintain biogeochemical cycles. The expected climate change is likely to have adverse effects on temperate forests and these will be augmented by additional risk factors such as air pollution and biotic and abiotic stresses.

The new type of forest damage occurring chiefly in the industrialized countries of the temperate zones also contributes to the man-made increase in the greenhouse effect to an extent not yet quantified, through premature dying of forest stands and a reduction of humus and biomass of surviving forest stands. Irrespective of the man-made increase in the greenhouse effect, measures must be undertaken or strengthened to reduce air pollution and its effects on forests. The aim of adjustment strategies is to secure sustained and comprehensive functioning of the forest with simultaneous maximum CO_2 fixation capacity of forest ecosystems. Forestry measures, such as selection of site-adequate tree species, use of suitable provenances, achievement of stable, diverse mixed stands, and preservation of genetic diversity, can counteract crisis-type disturbances in development to a limited extent only and over long periods. But nevertheless, they have to be introduced and/or strengthened now to be effective in time.

Because temperate forest stands tend to be intensively managed, and surplus agricultural land may be available, there may be promising opportunities to mitigate the greenhouse effect by expanding forest biomass in temperate zones.

4.2.2.3 *Costs of Forestry Countermeasures*

Some forestry adjustment strategies to changed climatic conditions can be carried out without large additional costs by adjusting silvicultural measures that have to be carried out in any case. The situation is different, however, if climate changes result in severely reducing the stability of stands and if selected measures for the stabilization of the stand have to be taken. Such costs are estimated at approximately U.S.$5 per hectare per annum. Furthermore, there might be a drastic increase in these costs if climate changes require a conversion to other tree species. As the degree of the damage strongly differs from region to region and as this is also true for the type of required forestry adjustment strategies, average costs for such adjustment measures cannot be reasonably assessed.

Determination of costs of reforestation and forest management in temperate zones is quite difficult for many reasons, including the diversity of situations found in countries. For example, besides the objective of carbon fixation, in many countries afforestation has to fulfill a productive, protective, and recreational function, all at the same time. The specific objectives and conditions for the respective measure strongly influence costs. Afforestation costs vary considerably, ranging from approximately U.S.$200 up to $2,000 per hectare, excluding possible opportunity costs of eliminating the present use.

Stand volume in forests with an open stocking can be increased by underplanting measures; the costs for such measures amount to approximately 50 to 75 percent of regular plantation costs. In forests with an already relatively closed stocking, the stand volume can be increased by an extended rotation period. Increased expenditure for the required stand tending can at a later stage be offset by a considerably higher revenue on account of an improvement in the structure of the assortment and the value. Short rotation wood crops may also provide high yields and give more flexibility in times of climate change.

4.2.2.4 *Constraints on Forestry Measures*

In the temperate zones there are only a few physical constraints on afforestation. They may result from continued pollution and, on some sites, also from the expected climate changes. The essential constraints—above all, in densely populated industrialized nations with intensive land use—are of a social nature, and opportunity costs for land use are high. Competing demands on land use by nature conservation, recreation, settlement, and traffic can make a transition to forestry use or afforestations considerably more difficult and expensive. As noted earlier, surpluses of agricultural products have also led to proposals to transfer significant areas of agricultural land to other uses, including forestry.

Overall, however, many questions remain to be answered before the potential contribution of forestry response strategies in temperate zones can be better quantified.

4.2.3 Special Issues on Tropical Forests

4.2.3.1 *Introduction to Tropical Deforestation and Climatic Concerns*

The development and ecological stability of countries with tropical forests is linked to the health of those forests. They contain half of the world's species of fauna and flora and provide raw materials, sustain rainfall on downwind agricultural land, maintain healthy fisheries and water supplies, and prevent soil erosion, dam siltation, and flash flooding. Global, regional, and local climate are linked to the health of tropical forests. Deforestation may be responsible for one-quarter to one-fifth of global anthropogenic carbon dioxide emissions, one to four-tenths of all (natural and anthropogenic) methane releases, as well as contribute to concentrations of nitrous oxides, ozone, carbon monoxide, and other gases implicated in global warming. Regionally, deforestation may interrupt moisture and latent heat transferred from the tropics to higher latitudes, influencing the climate of the temperate zone. Locally, partial or total removal of forest cover can cause drying of the microclimate, leading to an increase in natural fires that prevent natural forest regeneration of forests.

4.2.3.2 *Forest Carbon Pools and Forest Cover Statistics*

Tropical open forests (relatively dry scrublands and woodlands) and closed forests (90 percent of which are moist) contain about half of the terrestrial carbon pool. The closed forests represent the greatest store of carbon. In 1980 closed tropical moist and dry forests occupied an area of about 1.2 billion hectares. The distribution of this was 679 million, 217 million, and 306 million ha in Latin America, Asia, and Africa, respectively. A small number of countries, including Brazil, Burma, Colombia, Gabon, Guyana, Indonesia, Papua New Guinea, Venezuela, and Zaire, contain 80 percent of closed moist forest. Open forests occupied about 1.4 billion hectares. The distribution of this was 929 million, 363 million, and 67 million ha in Africa, Latin America, and Asia, respectively. Secondary forests (forest regrown after clearing), fallow forest (woody vegetation derived from forest clearing for shifting agriculture), and plantations do not store as much carbon as primary forest. In 1980 regenerating forest fallow occupied about 408 million ha, with 169 million, 166 million, and 73 million ha of this distributed in Latin America, Africa, and Asia, respectively. Plantations occupied 11.5 million ha, the distribution of which was about 5.1 million, 4.6 million, and 1.8 million ha in Asia, Latin America, and Africa, respectively (FAO, 1982).

4.2.3.3 *Estimates of Current Rates of Forest Loss*

Estimates for the period 1980–85 indicate that about 11.3 million ha of tropical forests were annually cleared and converted to other land uses (Table 4.2). Approximately 7.5 million ha of the annual clearing was in closed forest, with 57 percent, 25 percent, and 18 percent of this clearing occurring in Latin America, Asia, and Africa, respectively. About 3.8 million ha of the clearing was in open-canopy formations, with 62 percent, 33 percent, and 5 percent of this clearing occurring in Africa, Latin America, and Asia, respectively (FAO, 1988). Logging (mostly selectively in closed-moist forests) disturbed an additional 5 million ha per year in the same period (FAO, 1986). In 1980 the forestation (both reforestation and afforestation) rate was about one tenth of the deforestation rate (about 1.0

million ha/yr). While forestation has nearly doubled, the ratio to deforestation has remained at about one tenth the current rate of deforestation.

The current rates of forest loss, natural regeneration, reforestation and afforestation and forestation in 1990 are subject to debate. One recent, but unconfirmed study by Myers (1989) indicates that in 1989 the rate of clearing of closed tropical moist forests had doubled to 14 million ha/year. The FAO is developing a new survey of forest cover to be released in 1991 and by 1992 satellite data assessing the status of the world's tropical forests should be available from a joint space agency programme led by Brazil.

Table 4.3 lists the closed tropical moist forest deforestation rates for the top ten countries in the late 1970s based on FAO data and in 1989 based on Myers. One recent study (Myers, 1989) undergoing further review suggests that there is a trend of increasing deforestation rates, although differences in methodologies between the FAO and Myers studies may also account for the increase. The change in countries on the list and their relative positions may indicate the effect of economic, social, and political factors on rates of forest loss.

4.2.3.4 *Patterns and Causes of Deforestation*

The three main determinants of deforestation are: land conversion for agriculture and pasture; wood removals for fuelwood and inappropriate timber utilization; and public and private development projects (e.g., logging, mining, roads and dams—see Table 4.4). In the semi-arid tropics forest loss and land use conflicts are associated with natural and man-induced desertification. The extent of desertification in Africa, Asia (excluding USSR) and Latin America was about 1,536 million ha in the early 1980s (WRI et al., 1988).

Deforestation in the humid tropics is mainly due to clearance for agriculture, while in mountain and dry regions a substantial portion of the deforestation may be caused by the need to fell trees for fuelwood and fodder.

Land Conversion for Agriculture and Pasture

The clearing of tropical forests for cropland and pastures is the greatest cause of deforestation. An estimated 6.8 million ha of fallow and 3.9 million ha

TABLE 4.2: Estimates of Rates of Tropical Deforestation for 1980–85 and 1989 (Square Kilometers*/Year)

	FAO 1980–85 (%)	MYERS 1989 (%)
Tropical closed forest		
America	4.339 (57)	7.68 (55)
Africa	1.331 (18)	1.57 (11)
Asia	1.826 (25)	4.43 (32)
Total	7.496	13.68
Tropical open forest		
America	1.272 (33)	
Africa	2.345 (62)	
Asia	0.190 (5)	
Total	3.807	

* Square Kilometer = 10^6 ha

TABLE 4.3: Top Ten Countries in Terms of Closed Moist Forest Deforestation Rates (Square Kilometers/Year)

LATE 1970s (FAO, 1981)	(KM^2/YR)	1989 (MYERS, 1989)	(KM^2/YR)
Brazil	14,800	Brazil	50,000
Indonesia	6,000	Indonesia	12,000
Mexico	5,950	Burma	8,000
Colombia	5,100	Mexico	7,000
Philippines	2,900	Colombia	6,500
Côte d'Ivoire	2,900	Thailand	6,000
Nigeria	2,850	Malaysia	4,800
Peru	2,700	Zaire	4,000
Thailand	2,450	Nigeria	4,000
Malaysia	2,550	India	4,000

TABLE 4.4: Percent of Conversions of Tropical Forests Due to Different Land Uses (1980–1985)

	AMERICA	AFRICA	ASIA
Cropland	20	16	41
Pastures	17	−19	−1
Shifting Cultivation	25	46	49
Degraded Lands	38	57	11

Source: FAO (1987), FAO (1982).

Note: Mixed forest-pasture in Africa and Asia is being converted into more intensive land uses, usually agriculture, thus resulting in negative numbers in the table.

of closed forest may be cleared annually for agriculture; 1.3 million ha of fallow and 0.7 million ha of closed forest may be cleared for pasture annually (Houghton et al., 1985). Figures for open forests are not available. The increase in croplands and pastures may have accounted for 40 percent of the primary tropical forest conversion between 1980 and 1985 (FAO, 1987). According to 1980 figures of the U.S. Interagency Task Force on Tropical Forests, 100 million ha of land, much in the forest, could be brought into cultivation by the year 2000. The rate of expansion of croplands and pastures does not explain the rapid rate of loss of forests. Over-cropping and over-grazing may be permanently degrading productive lands, so that they must be permanently abandoned and replaced with new land cleared from primary forest to maintain a given level of agricultural activity (FAO, 1987) (Table 4.4).

Traditional, sustainable long-rotation shifting cultivation clears only fallow, so it is in balance with respect to carbon. It has largely been replaced by short-rotation shifting cultivation that degrades soil and other forms of unsustainable agriculture, which are expanding into carbon-rich primary forest, producing a net source of carbon, in response to growing populations.

Wood Removals for Fuelwood and Commercial Logging

Wood removed from tropical forests is used for two main purposes: 83 percent is mainly for fuelwood and charcoal, and 17 percent is for industrial roundwood (13 percent for local use and 4 percent for export); however, commercial logging practices damage a significant percentage of the trees left standing, resulting in total forest damage far greater than the removal rates entailed in selective logging (EC, 1989).

Fuelwood

Studies have led to two contradictory conclusions about whether fuelwood collection causes deforestation, contributing to the greenhouse effect. One recent study suggests that fuelwood harvesting accounts for little permanent loss of tree stock, with most fuelwood coming either from sustainable fuelwood production or from by-products of natural death or forest clearing. Considering the net balance of greenhouse gas production from wood burning, using more energy-efficient wood-burning cooking stoves to reduce fuelwood demand may actually increase emissions of greenhouse gases overall, since these stoves typically raise heat transfer efficiency at the expense of reducing combustion efficiency. As a result, emissions of carbon monoxide and more potent greenhouse gases such as methane and nitrous oxide may increase relative to the production of carbon dioxide, which is a less potent greenhouse gas (Leach, 1990).

By other estimates, demand for wood outstrips supply, especially in drier and mountain regions. About 0.5 million ha of closed forest and 2.0 million ha of fallow forest may be degraded or cleared for fuelwood annually (Houghton et al., 1985).

Whether or not fuelwood collection is presently contributing to a net decline in forest cover, it could potentially become a more significant source of emissions in the future if village wood lot establishment does not keep pace with the anticipated demand. In 1980 planting for fuelwood averaged 550,000 ha per year, a fifth of the 2.7 million ha that was needed to satisfy demand. To meet the projected fuelwood demand of 55 million ha in 2000, 2.7 million ha would need to be planted per year, given 1980 as a base year (Brown et al., 1988, citing John Spears of the World Bank).

Logging

Tropical forests and plantations supply about 10 percent of the world's demand for timber and pulp. Logging for timber occurs mainly in closed forests of the humid tropics. By the early 1980s about 13.25 percent of humid tropical forests had been logged. Commercially valuable species account for less than 10 percent by volume of tropical forests, so logging in the tropics is mostly selective over extensive areas. Only 2–10 commercially valuable trees are removed per hectare, but as many as 30–70 percent of the remaining trees are left damaged. If forests are allowed to regenerate, the net flux of carbon from selective logging may be near zero. Destructive logging practices, however, may damage forest productivity and slow regeneration. If logged areas are subsequently colonized and used as croplands, as happens in many African and Asian countries, the net effect is a loss of carbon from the land. Logging is expected to increase with growing timber demand in the future.

Public and Private Development Projects

Although it is recognized that building roads is necessary to develop remote regions, the associated timber harvesting, in many cases, may damage the forest by opening it to penetration by farmers who burn the forest for agriculture. Large-scale development projects in the forest, such as flooding for hydropower, mining, and use of forest for charcoal production to fuel industrial processes such as steel smelting, may also cause large amounts of forest loss. No estimates of forest lost from large-scale projects are available.

4.2.3.5 *Estimates of Current Emissions from Forest Land Clearing*

Estimates of the quantity of carbon dioxide, methane, nitrous oxide, carbon monoxide, ozone, and other gases released when forests are cleared are imprecise due to uncertainty about emission factors, the rate of deforestation, and the amount of carbon stored in vegetation and soils, and the effect of soil disturbance on the flux of methane and oxides of nitrogen. The data are, however, adequate to estimate the range of emissions.

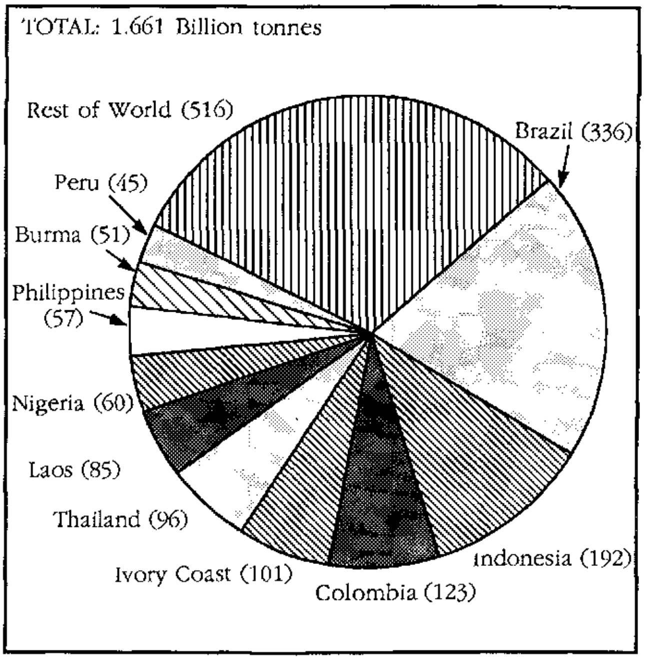
CARBON

Generally used estimates of the flux of carbon from tropical deforestation range from 0.4 to 2.6 billion tonnes of carbon (BTC) per year in 1980 (Houghton et al., 1987). In 1989 emissions from tropical deforestation may have been 2.0 BTC to 2.8 BTC according to certain preliminary estimates by Myers (1989). The scientists who addressed the São Paulo IPCC/RSWG Workshop in January 1990 were reasonably certain that in 1980 emissions were between 1.0 and 2.0 billion tonnes of carbon and that in 1989 emissions were between 2.0 and 2.8 billion tonnes of carbon. This range of estimates of 0.4 to 2.8 BTC is 6–33 percent of total anthropogenic emissions and represents 3–16 percent of the contribution to total greenhouse gas emissions in the 1980s (Houghton, 1989). Soil carbon losses may cause up to one third of carbon emissions associated with deforestation (Marland, 1988). Over half of 1980 emissions from deforestation were produced by six countries: Brazil, Indonesia, Colombia, Côte d'Ivoire, Thailand, and Laos (Figure 4.1). Those emissions totaled about 1.2 BTC in 1980. The actual emissions listed are subject to debate due to differences in assumptions about forest biomass and deforestation rates.

METHANE

Methane emissions from total tropical biomass burning (i.e., forests, savanna, and shrub-fallow) may range from 40 to 75 million tonnes of carbon per year (Houghton, 1989, based on Crutzen). Tropical biomass burning may contribute 8–11 percent of the annual global methane flux. This may represent about 1–2 percent of the contribution to total greenhouse gas emissions in the 1980s.

FIGURE 4.1: **Estimated Net Release of Carbon from Tropical Deforestation in 1980 (Teragrams Carbon)**

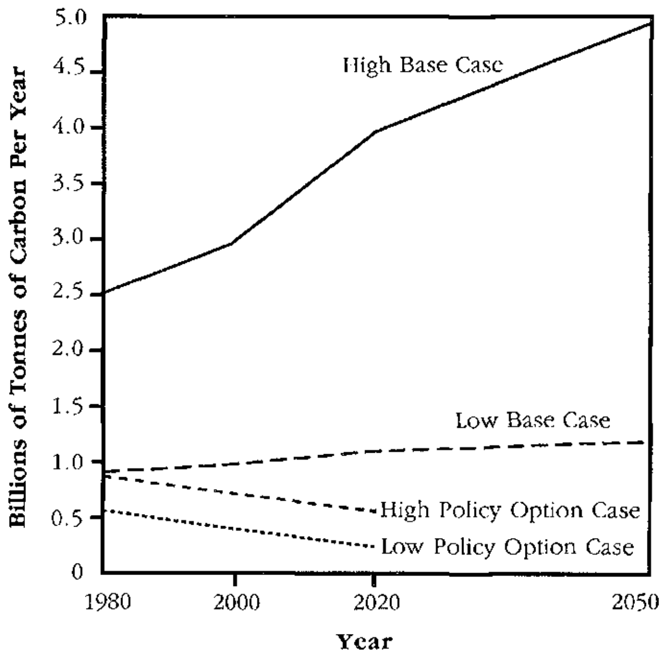


Note: The deforestation rates were derived from three estimates: FAO/UNEP (1981), Myers (1980, 1984), FAO (1983). The forest biomass was derived from two estimates: Brown and Lugo (1984), which is based on FAO/UNEP (1981), and Brown and Lugo (1982). The midpoint of total emissions was taken and the point estimate of country contribution to that total was determined based on FAO/UNEP (1981) rates and wood volumes.

Source: USEPA, 1989, based on Houghton et al., 1987.

FIGURE 4.2: Deforestation of Tropical Forests, 1980–2050: Two Base Case Projections of Increasing Carbon Emissions and Two Policy Option Cases for Decreasing Carbon Emissions

Long-term projections indicate that if current trends continue, as many as 1.5 to 2 billion ha of accessible tropical forests could be deforested in 50 to 100 years, releasing 120 to 335 BTC, depending on whether high or low biomass estimates are taken (Houghton, 1989).



Base Case Projections (Houghton, 1990b)
High: Population based deforestation rate and high forest biomass estimates
Low: Linear deforestation rate and low forest biomass estimates

Policy Option Cases (Grainger, 1989a)
High: Low increase in agriculture productivity relative to change in per capita consumption
Low: High increase in agriculture productivity relative to changes in per capita consumption

Note: See Appendix 4.1 for explanation.

NITROUS OXIDE

Nitrous oxide is naturally released from undisturbed soils although emission rates are uncertain. Higher emission rates are associated with fertilized, cleared, and pasture soils. Nitrous oxide is also produced during uncontrolled biomass burning.

CARBON MONOXIDE AND OZONE

About 5–10 percent of the carbon emitted in biomass burning is in the form of carbon monoxide. Although not a greenhouse gas, it indirectly increases the concentration of methane. The oxidation of carbon monoxide also produces ozone, a greenhouse gas in the lower atmosphere (Houghton, 1989). Burning to clear forest in the Amazon during the dry season almost triples the levels of carbon monoxide and ozone in the atmosphere (Kirchoff et al., 1990).

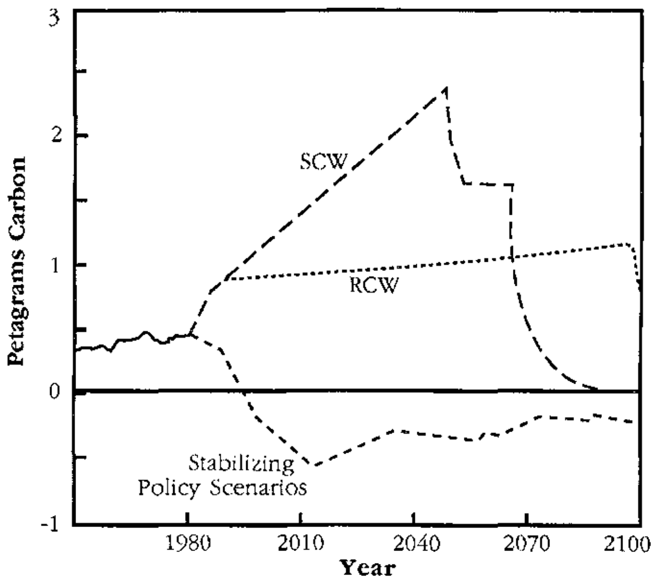
4.2.3.6 *Estimates of Future Forest Loss and Emissions*

Future greenhouse gas emissions are difficult to predict because of uncertainties about forest biomass, as well as population and economic growth rates. Two base case emissions projections by Houghton (1990b) suggest that emissions could range between 1.1 and 3.9 BTC in 2020 and 1.2 to 4.9 BTC in 2050. The low-bound estimates are from the low base case, which assumes low biomass and linear deforestation rates. The high-bound estimates are from the high base case, which assumes high biomass and population based deforestation rates (Figure 4.2 and Appendix 4.1). The country-by-country emissions for these two base cases for 1980 through 2050 are given in Appendix 4.2. In the slowly changing world scenario (i.e., continuing poverty, unsustainable agriculture, and population growth) the deforestation rate increases with population to 34 Mha/yr by 2050, releasing 2 BTC per year. As a result, Asia's unprotected forests are exhausted. After this date, emissions decline, and then fall sharply around 2075 with the loss of remaining African and then Latin American forests.

In a rapidly changing world (i.e., increased agricultural productivity, etc.) deforestation rates might stabilize at 15 million ha per year, releasing 1 BTC per year from 2000 to 2100, when emissions

FIGURE 4.3: CO_2 Emissions from Deforestation

Figure 4.3 illustrates three long-term emission scenarios developed by USEPA (1989) based on low forest biomass estimates. One scenario is based on a slowly changing world, one is based on a rapidly changing world and one involves a massive forestry response strategy to combat the buildup of carbon dioxide in the atmosphere.



SCW: Slowly changing world scenario, i.e., continuing poverty, unsustainable agriculture, and population growth.
RCW: Rapidly changing world, i.e., increased agricultural productivity, etc.
1 Petagram = 1 billion tonne

Sources: Lashof and Tirpak, 1989.

would fall as all remaining forests are exhausted.

Under an ambitious stabilizing policy stopping deforestation by 2025, and planting 1000 Mha of trees by 2100 in tropical and temperate zones, the biosphere would become a carbon sink by 2000, with absorption of carbon from the atmosphere peaking at 0.7 BTC per year in 2025.

Under policy option cases modeled by Grainger, decreases in the rate of deforestation would be possible. The high policy option case and low policy option case assume declining deforestation based on differing levels of improvements in agricultural productivity in relation to changes in food consumption per capita. Under the low and high policy case options, carbon emissions might be reduced by at least 40–70 percent, from between 0.5 (low case) to 0.8 (high case) BTC in 1980 to between 0.2 (low case) to 0.5 (high case) BTC per year in 2020 (Grainger, 1989a) (Figure 4.2; See Appendix 4.1 for assumptions).

4.2.3.7 *Strategies to Reduce Emissions: Types of Response Options*

Climate change offers an unusual challenge to forest planning and policy development. It is very important that countries begin the task of understanding the full social and economic consequences of continued deforestation, and the need to promptly examine options to slow forest loss. Quantitative and qualitative analyses of the costs and benefits of current forest policies, and their consequences for greenhouse gas emissions, need to be undertaken in the next few years. Policy options to control greenhouse gas emissions through forestry practices fall into three major categories:

1) Options to reduce forest sector sources of greenhouse gases:
   - reduce forest clearing for shifting agriculture by substituting sustainable, intensified, sedentary techniques, including agroforestry;
   - reduce frequency and amount of forest and savanna consumed in biomass burning to create and maintain pasture/grasslands;
   - reduce forest loss due to public development projects, through environmental planning and management;
   - improve efficiency of cookstove and industrial biomass use;
   - reduce damage to standing trees and soils during timber harvest; and
   - reduce soil carbon loss, via soil conservation farming practices and other management techniques.
2) Maintain existing sinks of carbon in forest systems:
   - conserve standing forest as stocks of carbon through establishment of protected areas and sustainable management;
   - introduce sustainable harvesting methods to reduce tree damage; and
   - establish sustainable extractive reserves and natural forests.

3) Expand carbon sinks through sustainable forest management:
   - improve productivity of existing forest lands;
   - establish plantations on available pasture/savanna and cropland, marginal land, degraded land;
   - expedite natural regeneration of deforested land; and
   - increase soil carbon storage through soils management.

Analyses of the benefits of potential response options under these three general strategies are summarized below.

Strategy 1: Options to Reduce Forest Sector Sources of Greenhouse Gases

Reduce forest clearing for shifting and sedentary agriculture by substituting sustainable cropping systems. One important policy option to slow deforestation is to reduce forest clearing for agriculture. One scenario of halting deforestation envisages replacing 80 percent of slash-and-burn with sustainable agriculture (Lashof and Tirpak, 1989). Expansion of the agricultural frontier into tropical forest could be curbed by:

- introducing crop mixes, planting and management systems, and improved genetic strains to increase productivity per unit area faster than increasing food consumption per capita. Inputs of fertilizers, water, and capital at varying levels will be necessary to achieve adequate agricultural intensification and sustainability; however, emphasis should be placed on R&D in "higher knowledge, lower external input" agricultural systems, since high-input systems are expensive and not feasible in many areas. Development of cash crops as well as subsistence food crops should be emphasized, so that farmers may acquire cash needed to invest in inputs;
- focusing agricultural development efforts on sites with adequate soils that are alternatives to tropical forests, such as savanna, pasture, and underutilized croplands;
- intensifying management on existing pasture to increase site productivity, by introducing appropriate technologies such as optimized foraging strategies, fertilization, mechanization, and improved livestock management.

Long-term research in the Peruvian Amazon indicates that for every ha in crop production converted to sustainable practices, 5–10 ha of forest might be saved (Table 4.5). Research on sustainable systems in Peru, Nigeria, Brazil and elsewhere is promising, but needs to assess the potential of large-scale introductions on a variety of soil types, and to assess the net greenhouse gas emission (tradeoffs in emissions among gases) benefits of introducing various competing systems. Wet rice cultivation, while very sustainable in the humid tropics, is also a major source of methane emissions. Cross sectoral analyses are needed to evaluate the new management and biotechnology techniques suggested in the AFOS Agriculture Workshop, before specific practices are recommended.

Strategy 2: Maintain Existing Sinks of Carbon in Forest Systems

Slowing or halting deforestation may offer the greatest net social and ecological benefits, most likely at comparatively low costs per ton of carbon emissions avoided, of the response options reviewed by AFOS (see Figure 4.4). Halting the conversion of tropical forests would immediately reduce CO_2 emissions by perhaps 1–3 BTC per year, depending on actual current emission rates.

TABLE 4.5: **Forest Saved by Sustainable Agricultural Techniques in the Peruvian Amazon**

Sustainable Agricultural Practices	Number of ha of Forest Saved per ha in Sustainable Use
Flooded Rice	11.0
Legume-Based Pasture	10.5
High Input	8.8
Low Input	4.6
Agroforestry	not determined

Source: Sanchez, 1988.

Response options to protect standing forest include:

1. CONSERVE STANDING FOREST AS STOCKS OF CARBON, BY EXPANDING PROTECTED FORESTS AND EXTRACTIVE RESERVES.

The expansion of protected tropical forest has accelerated since 1970 from very low levels. Substantial new areas of existing forest could be designated for protection from encroachment. Expansion of protected areas could also assist developing countries to conserve the tropical biodiversity for long-term socio-economic benefits.

Non-destructive resource use in extractive reserves, where rubber, nuts, and other products are harvested for market without cutting forest, could be greatly expanded, if markets are developed and land is legally protected, following Brazil's progressive experiments in Amazonia. Identification of new protected area should take into account the effects of and changes in forest conservation needs that would accompany climate change, such as the need for species migration corridors.

2. INTRODUCE SUSTAINABLE HARVESTING AND NATURAL FOREST MANAGEMENT METHODS TO REDUCE TREE DAMAGE.

Widespread introduction of sustainable timber and forest product extraction techniques from the primary forest that damage fewer trees left standing than current methods would help assure long-term carbon storage. Improved forest management could increase forest productivity. Approximately 137 million ha of logged forest could benefit from enrichment planting and regeneration because current selective logging techniques reduce long-term productivity by damaging 30–70 percent of the species left behind (Grainger, 1989b).

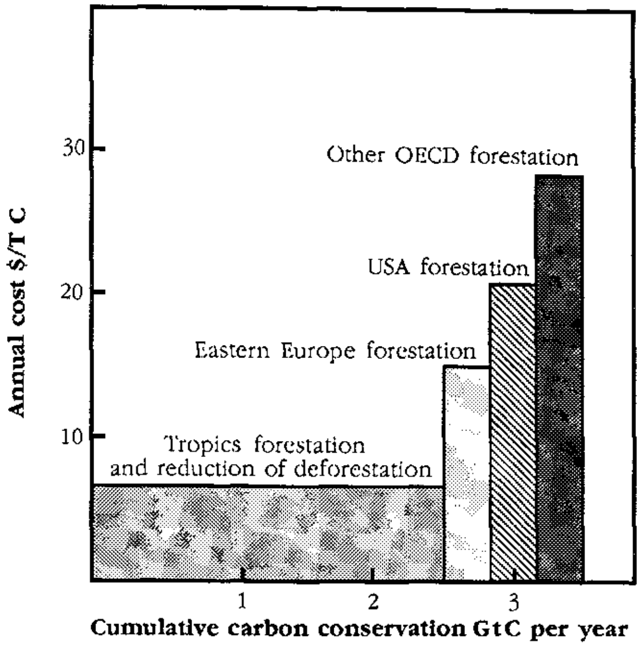
Strategy 3: Expand Carbon Sinks Through Sustainable Forest Management and Intensified Forest Management

Options under review by analysts include the following:

1. ESTABLISH PLANTATIONS ON AVAILABLE PASTURE/SAVANNA AND CROPLAND, MARGINAL LAND, DEGRADED LAND.

The increasing demand for wood products and biofuels provides an opportunity to promote the establishment of plantations on degraded lands to play a role in absorbing carbon dioxide from the atmosphere.

FIGURE 4.4: **Regional Average Costs of Forest Management Measures***



* The figure is taken from: McKinsey & Company: Protecting the Global Environment: Funding Mechanisms (Appendices), which was prepared for The Noordwijk Conference, The Netherlands, November 1989.

Source: FAO, WRI, McKinsey analysis.

There are two estimates of land available for forestation. According to Grainger (1989b), a total of 621 million ha of land may be available for forestation in the tropics. Of this total, 418 million ha are in the dry and montane regions and 203 million ha are forest fallow in the humid areas. According to Houghton (1990a), up to 865 million ha of land in the tropics are available for forestation. Of this total, there may be about 500 million ha of abandoned lands that previously supported forest in Latin America (100 million ha), Asia (100 million ha), and Africa (300 million ha). The additional 365 million ha could be available only if increases in agricultural productivity allowed this land to be removed from production. If this upper estimate of 865 million ha of potentially available land were reforested, a total of 150 million BTC could be removed from the atmosphere after forest maturation (Houghton, 1989).

Two types of forest could be created:

- protection forests (for watershed protection/ erosion control; ecosystem restoration; preservation; carbon stock; biodiversity), and
- production forests (biofuel plantations; industrial timber; agroforestry; community woodlots; carbon pump).

The São Paulo workshop members concluded that local fuelwood and shelterbelt options may be cost effective, but may lack potential for a major global impact. Agroforestry is believed to have both low costs and substantial global potential. Biofuel and industrial options are believed to have higher costs, but large global potential. Unfortunately, establishing plantations in the next few decades is unlikely to stop the spread of unsustainable logging in natural forest, since the growth of mature species of wood quality comparable to natural forests may take 30 to 70 years.

2. AFFORESTATION SCENARIOS

A wide variety of afforestation options could be pursued on a global basis. For example, three scenarios of replanting evaluated by Grainger (1989b) include planting 6 million ha/year over 10 years, 8 million ha/year over 20 years, or 10 million ha/year over 30 years to offset 5 percent, 13 percent, or 26 percent of the 5.5 BTC currently released from burning fossil fuels annually (Table 4.6). The estimated costs total \$2.4, \$3.0 or \$4.0 billion per year, respectively (Table 4.7). Options trading-off time and money to reach specific planting targets are presented in Table 4.7. The shorter the time-frame to reach a given level of planting and carbon uptake, the higher the annual cost of planting. The 13 percent reduction scenario achieved over 20 years would lead to an additional annual harvest of 2.6 billion cubic meters, which would allow global forest production to meet the anticipated demand for wood in 2030 (Grainger, 1989b).

National and global scale forestation scenario building to offset climate change is currently limited by incomplete and not widely representative tree growth rate, forest standing biomass, and establishment cost data. Present estimates may be high or low by a factor of 3–10, especially if economies of scale are realized. For example, recent cost estimates in the United States for a 20-million-ha federal planting programme have declined by about 40 percent during programme analysis and design, as better data became available. In the United States, estimated tree establishment costs for a 5 percent CO_2 offset programme involving about 12 million ha have now come down to around U.S.\$320/ha. Such a programme could capture carbon at about \$9 per ton carbon (most likely a very low cost per ton, compared with other options available), according to the U.S. Forest Service.

TABLE 4.6: Afforestation Strategies to Achieve a Range of Reductions in Annual Fossil Fuel CO_2 Emissions of 5.5 Billion Tonnes of Carbon

% CO_2 Reduction	Total Area Planted (ha 10^6)	Planting Rates/Yr (ha 10^6) 10	20	30	50
26	300	30	15	10	6
13	150	15	8	5	3
5	60	6	3	2	1

Note: Assumes average growth rate of 15 cubic meters/yr/ha or 3–4 tonnes carbon
Source: Grainger, 1989b.

TABLE 4.7: Costs of Planting Scenarios to Achieve a Range of Reductions in Annual Carbon Dioxide Emissions from Fossil Fuels

% CO_2 Reduction	Total Area Planted (ha 10^6)	Total Cost	Costs (US\$ Billion/Year) Over Planting Period 10	20	30	50
26	300	120	12.0	6.0	4.0	2.4
13	150	60	6.0	3.0	2.0	1.2
5	60	24	2.4	1.2	0.8	0.5

Note: Costs of establishing a forest plantation vary from U.S.\$230 to \$1,000 per ha, with an average of \$400 per ha. Harvest cost per ha may be U.S.\$6,750 (Sedjo and Solomon, 1988), but probably would be offset by revenues. Maintenance costs would be extra, and land rental or purchase costs relatively low.
Source: Grainger, 1989b.

3. IMPROVE PRODUCTIVITY OF EXISTING FOREST LANDS

If more species and size classes of trees were used for timber, then efficient harvest and management would be more feasible, and less extensive areas would be logged. Development of technologies and marketing methods to promote greater use of lesser-known species, using harvests based on detailed forest inventories and management plans, would improve yields per unit area.

4.2.3.8 *Policy Options*

National Level Policy Options Available to Improve Forest Management in Response to Climate Change

Because of the important role of the forestry sector in ecological cycles and economic development, there is a need to develop recommendations at both national and international levels. Although uncertainties about the rate and extent of climate change remain, the following are a number of steps that nations could take:

1) In the context of the review of the Tropical Forestry Action Plan currently under way, adopt clear objectives for the conservation, and/or sustainable development of tropical forests in national development plans, including forests associated with agricultural lands, commercial-use forests, and extractive reserves and other protected areas; and reconcile conflicts between current forest management and programmes proposed and initiated under TFAP.

2) Strengthen tropical forest management use of near real-time remote sensing analysis of biomass burning and of forest loss patterns. Coordinate national and multilateral space and development agency imagery programme data collection and analysis with national forestry regulatory and enforcement programmes.

3) Estimate current and future emissions of greenhouse gases from the tropical forest sector, and potential reductions of emissions from various offset planting and management scenarios.

4) Produce and implement national forestation plans for degraded tropical forest lands, based on cost, feasibility, and true net social benefits analyses.

International Response Options Available to Slow Forest Loss and Stimulate Forestation

A number of response options are available that were specifically identified at the Brazil workshop. These include:

1. DEVELOPMENT OF A WORLD FOREST CONSERVATION PROTOCOL IN THE CONTEXT OF A CLIMATE CONVENTION PROCESS THAT ALSO ADDRESSES ENERGY SUPPLY AND USE.

The AFOS São Paulo Workshop final statement recommended, after discussion and agreement in plenary, that the IPCC support the development of a global forestry protocol to apply to tropical forests as well as temperate and boreal forests in all countries, in the context of a climate convention process that also addressed energy supply and use. The statement agreed upon at the São Paulo workshop for a workshop recommendation calling for development of a World Forest Conservation Protocol was:

> Consideration of forestry issues, and of tropical forestry issues in particular, must not distract attention from the central issue of global climate change and the emission of greenhouse gases attributable to the burning of fossil fuels by developed countries. No agreement on forests and global climate change will be reached without commitments by developed countries on greenhouse gas emissions. The groups recognized that the conservation of tropical forests is of crucial importance for global climatic stability (particularly having regard to the important contribution of tropical forest destruction to global warming, through emissions of carbon dioxide, methane, and other trace gases), but of more crucial importance for national economic and social development, for the conservation of biodiversity and for local and regional climatic and environmental reasons. The Workshop recommended that the IPCC support the development of a forestry protocol in the context of a climate convention process that also addressed energy supply and use. The Workshop concluded that the specific elements of such a protocol are a matter for international negotiations. These elements may include: fundamental research, tropical forest planning, measures to use, protect, and reforest,

international trade, financial assistance and the advantages and disadvantages of national and international targets.

The objective should be to present more concrete proposals on the occasion of the UN Conference on Environment and Development, to be held in 1992.

In light of the above, it is recommended that a World Forest Conservation Protocol, covering temperate, boreal, and tropical forests, be developed in the context of a climate convention process that also addresses energy supply and use, as noted by the January 1990, IPCC/RSWG Tropical Forest Workshop in São Paulo, Brazil and that in accordance with UNGA Resolution 44/207, operative paragraph 10, a meeting of interested countries from both the developed and developing world and of appropriate international agencies be held to identify possible key elements of such protocols and practical means of implementing them. Such a meeting should also develop a framework and methodology for analyzing the feasibility of the Noordwijk remit, including alternative targets, as well as the full range of costs and benefits.

All countries should make a contribution to the solution of the global warming problem. The São Paulo Workshop stated:

> Although forests can assist in mitigating the effects of atmospheric carbon build-up, the problem is essentially a fossil fuel one and must be addressed as such. In this way, and as a general principle, the final report of the present IPCC Workshop on Tropical Forests, while putting tropical forests in the overall context of global warming, should make it clear that the burden of response options is not to be placed on developing countries and thus should state clearly that all countries should make a contribution to the solution of the global warming problem. The temperate forest dieback (caused by acid rain), as analogous to tropical deforestation (caused by tropical people's attempts to satisfy basic human needs), could be specifically mentioned in such a context.

It should however be noted that recent findings indicate that forests may be adversely affected throughout the world by a variety of causes, only one of which is acid deposition.

The São Paulo Workshop further noted:

> Forests cannot be considered in isolation, and solutions must be based on an integrated approach which links forestry to other policies, such as those concerned with poverty and landlessness. The forest crisis is rooted in the agricultural sector and in people's needs for employment and income. Deforestation will be stopped only when the natural forest is economically more valuable than alternative uses for the same land.

2. SUMMARY OF OTHER OPTIONS IDENTIFIED BY SÃO PAULO WORKSHOP SESSIONS

a) Increase Support for Tropical Forestry Action Plan (TFAP).
TFAP offers the framework within which national plans for heightened forest management can be developed. Priorities within the TFAP could be reviewed by member countries and FAO to consider how they can be strengthened to address climate change concerns. Meeting resource needs for TFAP should be a priority.

b) International Tropical Timber Organization (ITTO).
Consideration should be given to strengthening the role of ITTO to develop international guidelines to encourage:
- sustainable forest management techniques, including national legislation requiring management of forest for sustained wood production;
- an assessment of incentives for sustainable forest management including the feasibility of labeling.

c) Development Assistance Organizations and Development Banks.
The development banks—IMF, FAO, UNEP—and other multilateral or bilateral international organizations could help tropical forest countries achieve conservation and sustainable development of forests by:
- requiring analyses of climate change implications, potential greenhouse gas emissions, and forestry response programmes in their review of project proposals;
- expanding greatly aid and investment flows to forestry;

- expanding debt relief via renegotiation of debt, and debt for conservation exchanges; and
- linking structural adjustment measures to alleviation of climatic impacts and gas emissions reductions.

d) Role of International Forestry Organizations. International forestry organizations have, as a rule, not yet developed programmes or guidelines to member states on forestry and climate change. Potential institutional initiatives could include:

- adding forestry and climate research and development programmes to the CGIAR system (Consultative Group on International Agricultural Research), at least one on each major tropical continent, to conduct and disseminate research results and beneficial field practice guidelines to foresters re-managing forests for adaptation to and mitigation of climate change;
- urging International Union of Forestry Research Organizations (IUFRO) to develop a coordinated set of research programmes on technical silvicultural, ecological, and management issues pertaining to climate change.

4.3 AGRICULTURE RESPONSE STRATEGIES

Agricultural activities currently produce approximately 14 percent of the greenhouse gases emitted globally. Agriculture is a significant contributor to the increasing atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, and to emissions of nitric oxide and carbon monoxide. In the development of options to reduce greenhouse gas emissions from agricultural activities, it is important to recognize that the economies of many developing countries are strongly dependent on agriculture.

Agricultural systems need to be assessed as whole systems. Their potential as sinks for carbon and nitrogen must be evaluated, as well as their role as sources. Trade-offs of the various gases need to be evaluated, and the systems' capacities to alter carbon and nitrogen cycles must be examined. In addition, the systems must be evaluated in terms of energy inputs and losses from sectors providing goods and services, production, storage, transportation, processing, and marketing.

4.3.1 Summary of Agricultural Emissions of Greenhouse Gases

Agriculture contributes to the emissions of greenhouse gases through the following practices: flooded rice cultivation, nitrogen fertilizer use, ruminant animals, improper soil management, land conversion, and biomass burning. The appendix to this section illustrates the level of emissions and agricultural activities on a country by country basis. Globally, rice cultivation, ruminant animals, and biomass burning are estimated to contribute approximately 15, 9, and 8 percent respectively, of total methane production; methane, in turn, accounts for about 20 percent of current greenhouse gas emissions. The use of nitrogen fertilizers is estimated to account for between 0.2 and 20 percent of the current global source of nitrous oxide, nitrous oxide representing 5 percent of current greenhouse gas emissions. Land clearing and biomass burning contribute between 10 and 30 percent of current greenhouse gases, contributing to increases in emissions of carbon dioxide, methane, nitrogen oxides, and carbon monoxide. Emissions from these sources are expected to increase substantially over the next several decades due to population and economic growth and the associated expansion and intensification of agricultural activities.

- Population is estimated to grow at an average of 1.3 percent per year, with global population reaching 8.2 billion by 2025.
- The land area in cropland or pasture is increasing while global forest area is declining.
- Area under cultivation in developing countries is projected to increase at a rate of 1.2 percent per year through 2025, which would result in a 50 percent increase in current levels by 2025.
- Area devoted to rice cultivation is projected to increase from 148 million hectares in 1984 to 200 million hectares by 2025 globally. Methane

from rice cultivation may increase nearly 35 percent by the year 2025.

- Production of meat and dairy products is projected to increase by over 45 percent between 1990 and 2025 and to result in a similar increase in methane emissions.
- In general, land under cultivation is being more intensively cultivated, and the intensity of nitrogen fertilizer use is increasing. Nitrogen fertilizer use is estimated to increase by a factor of five over 1985 levels by 2025 in developing countries (see Table 4.8). Globally, fertilizer use is projected to nearly double over the same time frame. Nitrous oxide emissions could increase by 70–110 percent, although technological advances in fertilizer formulations may significantly reduce these potential increases.
- Emissions of methane are estimated to increase from 511 million metric tonnes in 1985 to about 730 million metric tonnes in 2025.
- Agricultural sources will be contributors to these increases. In addition, emissions of nitrous oxide may increase from 12.4 million tonnes in 1985 to some 16 million tonnes in 2025. Fertilizer use may play a large role in this increase (Figure 4.5).

TABLE 4.8: **Projected Levels of Agricultural Activities in 93 Developing Countries***

	PROJECTED AREA FOR CROPS (MILLION HA)		PROJECTED NITROGEN FERTILIZER USE (MILLION TONNES)	
	1985	**2025**	**1985**	**2025**
Rice	106	152	5.2	22
Wheat	61	106	2.3	15
Maize	59	96	1.1	7
Other Cereals	92	142	0.4	2
Legumes	82	161	0.5	3
All Others	163	288	2.1	9
Total	563	945	11.6	58

* Does not include China

Source: FAO projections given at workshop.

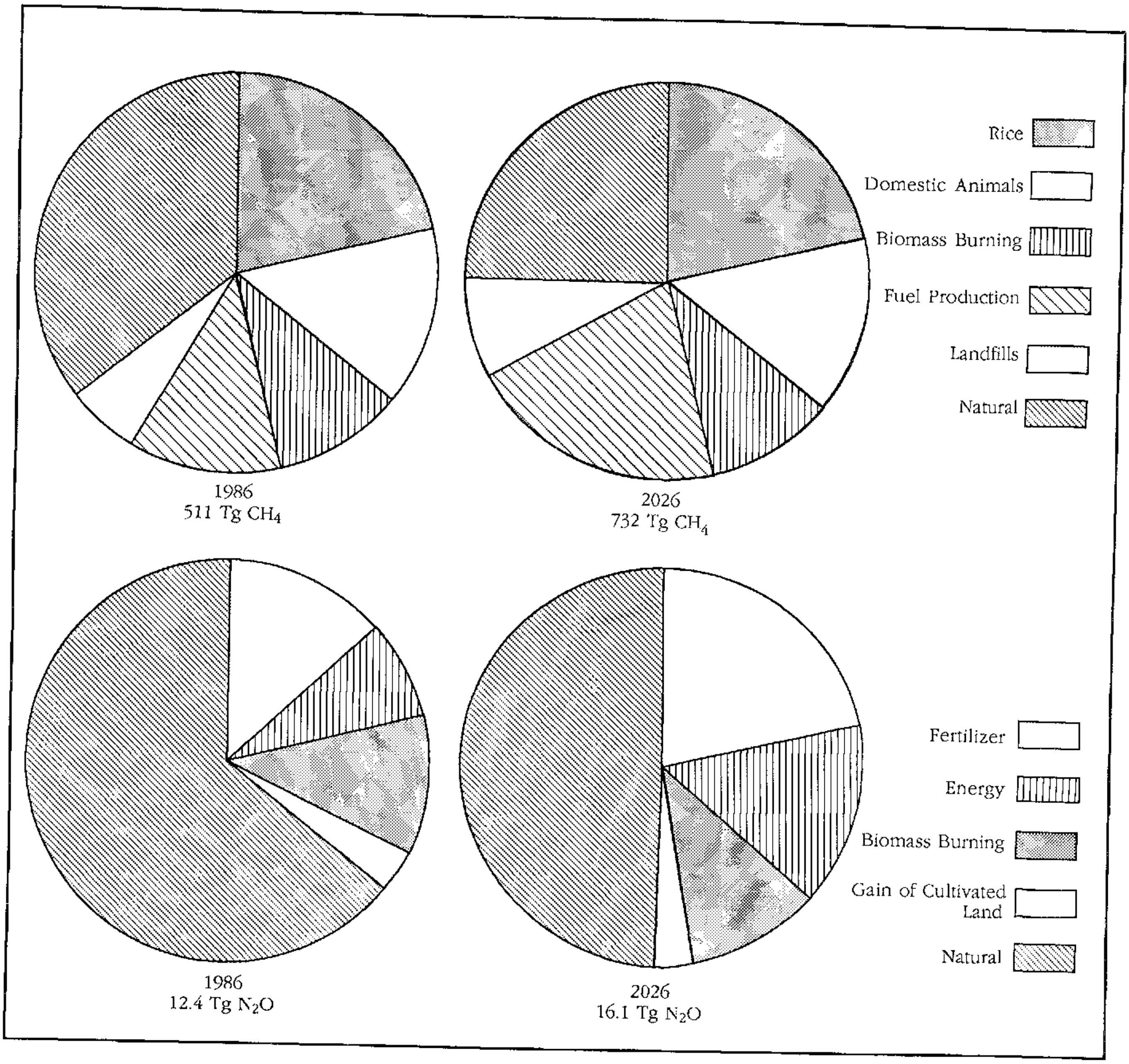
4.3.2 MEASURES AND POLICY OPTIONS

Future agricultural practices and policies can affect the levels of greenhouse gas emissions from agricultural sources and contribute to stabilization of their atmospheric concentrations. However, reducing emissions from one or two sources will not be sufficient. For example, in order to stabilize methane concentrations, reductions in methane emissions from flooded rice fields, livestock systems, and biomass burning as well as from other anthropogenic sources, will be necessary. Similarly, modifications in nitrogen fertilizer use, land use conversion, and crop systems will be necessary parts of multisectoral strategies to achieve the reductions to stabilize atmospheric concentrations of carbon dioxide and nitrous oxide.

The opportunities for reducing gas emissions in the near-term which appear to be economically viable in their own right consist of the following:

- *Biomass burning:* Biomass burning might be reduced through fire control, education and management programmes, as well as the introduction of the use of appropriate alternative agricultural practices. Agricultural systems dependent on the removal of biomass (by burning high-yield grain crops) may be modified to provide opportunities for increasing soil organic matter and reduction of greenhouse gas emissions or removal for use as an alternative fuel source.
- *Livestock systems:* Methane emissions can be reduced through management of livestock wastes; expansion of supplemental feeding practices for livestock; and increased use of production- and growth-enhancing agents, with appropriate safeguards for human health and taking into account legitimate consumer concerns.
- *Fertilizer use:* Nitrous oxide emissions may be reduced by using improved fertilizer formulations and application technologies, and through judicious use of animal manure.
- *Sustainable agricultural practices:* Where appropriate, minimum- or no-till systems are recommended for those countries currently using tillage as part of the annual cropping sequence. These tillage systems may yield additional ben-

FIGURE 4.5: **Projected Emissions of Greenhouse Gases**



efits such as direct energy savings, improved soil tilth and increase of soil organic matter.

- *Marginal lands:* Areas marginally suitable for annual cropping systems should be shifted to perennial cover crops for fodder or pastoral land uses of woodlands, if soils are suitable. Such actions could increase carbon uptake, both in the vegetation and soil, and could yield other benefits such as reduced soil erosion, improved water infiltration and quality, and delayed stream flow.

Longer-Term Options Requiring Research and Demonstration

Several opportunities for reducing greenhouse gas emissions and enhancing carbon sinks have been identified for the longer term. In general, these opportunities must be developed, demonstrated, and assessed in terms of greenhouse gas reductions and the full range of potential costs and benefits. These alternatives must maintain or enhance the productivity of the agricultural systems. This will require substantial research efforts focused on better understanding of the processes by which these gases are emitted, further investigation of promising options, and better field measurement devices.

General opportunities for reducing emissions of these gases have been identified:

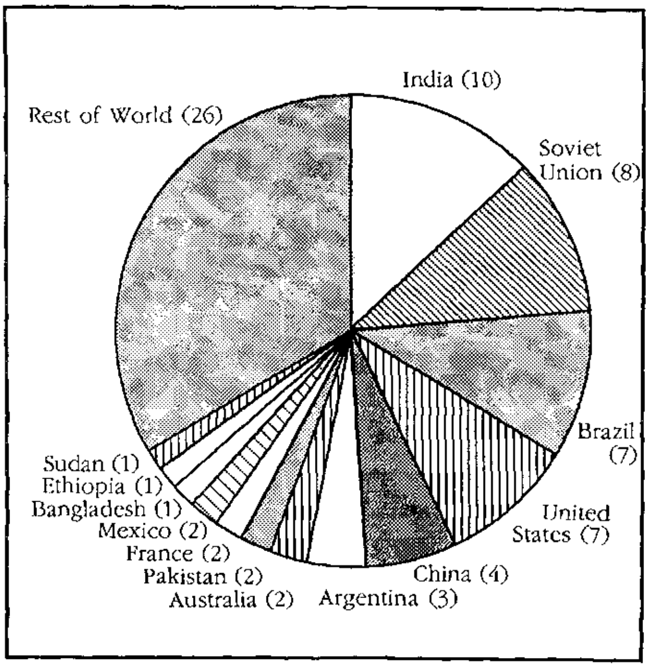
- A comprehensive approach including management of water regimes, development of new cultivars, efficient use of fertilizers, and other management practices could lead to a 10–30 percent reduction in methane emissions from flooded rice cultivation, although substantial research is necessary to develop and demonstrate these practices. A 10 percent reduction in emissions from rice systems might contribute about 15–20 percent of the total reduction required to stabilize atmospheric concentrations of methane.
- Through a number of technologies it appears that methane emissions from livestock systems may be reduced by up to 25–75 percent per unit of product in dairy and meat production. The net effect of such improvements depends upon the extent to which such methods can be applied to domestic ruminant populations, which will vary greatly from country to country. However, each 5 percent reduction from animal systems could contribute 6–8 percent toward the reduction necessary to stabilize methane in the atmosphere.
- Fertilizer-derived emissions of nitrous oxide potentially can be reduced (although to what extent is uncertain) through changes in practices such as using controlled-release fertilizers, improving fertilizer-use efficiency, and adopting alternative agriculture systems.
- Trace gas emissions from biomass burning, land conversion, and cropping systems may be reduced through widespread adoption of improved agricultural practices, optimizing use of fertilizer and organic amendments, and improved pasture management and grazing systems. These gains may be offset by pressures of increasing population and increased demand for food and fiber production. In addition, policies associated with production, processing, storage, transportation, and marketing need to be examined to derive the optimum effectiveness from research, technological developments, and land use practices. Analyses are needed on economic incentives, taxes, pricing and trade barriers, cultural practices, technology transfer measures, education and information programmes, and international financial assistance measures.

4.3.3 INTERNATIONAL AND INSTITUTIONAL NEEDS

A broad range of institutional issues must be addressed in order to ensure that the objectives of increased global food security and reduced greenhouse gas emissions can be met in the future. Among the options that governments, international organizations and intergovernmental bodies such as IPCC should consider are the following:

- A series of agricultural workshops to assess new information on agricultural production and emission forecasts, exchange information on the effectiveness of new technologies and man-

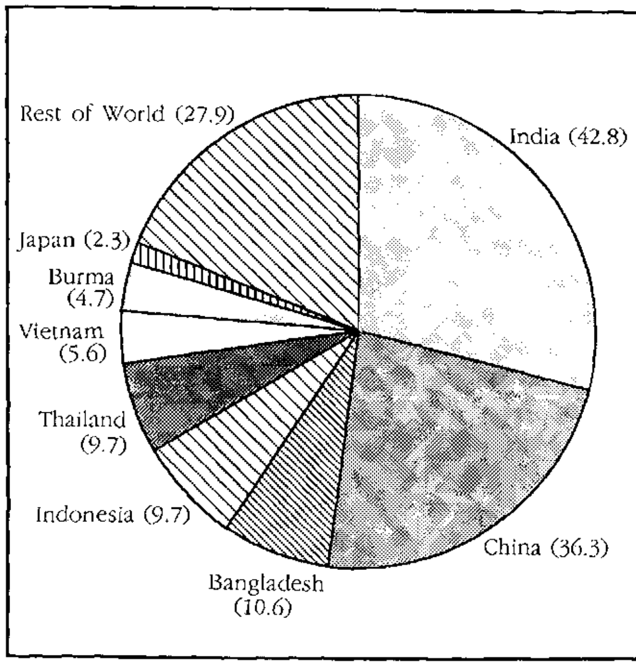
FIGURE 4.6: **Emissions of Methane by Domestic Animals, 1984 (Teragrams of Methane)**



Distribution of the total methane emissions from domestic animals of 76 Tg CH_4. India, the Soviet Union, Brazil, the United States, China, and Argentina together account for just over 50 percent of the animal CH_4 emissions. Currently, approximately 20 percent of the total anthropologenic CH_4 emissions is due to domestic animal populations.

Source: Lerner et al., 1988.

FIGURE 4.7: **Rice Area Harvested, 1984 (Million Hectares)**



Distribution of the total harvested rice paddy area of 148 million ha. Five Asian countries, India, China, Bangladesh, Indonesia, and Thailand accounted for 73 percent of the 1984 rice acreage.

Source: IRRI, 1986.

agement practices, and evaluate the potential impact of agricultural policies. These agricultural workshops should address the institutional and economic issues particular to the major agricultural sources of emissions, such as biomass burning, temperate agricultural practices, livestock emissions, and emissions from rice cultivation.

- An international symposium in 1991 or 1992 to assess current information on agricultural greenhouse gas emissions, practices, technology transfer, and extension service requirements.
- Guidelines for future research at national and international institutions such as FAO, CGIAR, and others to address the need to investigate impacts of climate change and options for reducing emissions.
- An international symposium in 1991 or 1992 on biomass burning, its contribution to greenhouse gas emissions, and practices and policies to reduce emissions.

4.3.4 Summaries from Agricultural Workshop

More specific findings and recommendations are presented in the following sections. These are summaries of consensus documents produced during multiple-day discussions at the IPCC workshop on agricultural systems.

The sections are divided as follows:

- Greenhouse Gas Emissions from Flooded Rice Cultivation
- The Role of Managed Livestock in the Global Methane Budget
- Tropical Agriculture: Fertilizer Use, Land Use Conversion, and Biomass Burning
- Temperate/Boreal Agricultural Systems: Fertilizer Use, Land Use Conversion, and Soil Management

4.3.4.1 *Greenhouse Gas Emissions from Flooded Rice Cultivation*

Flooded rice fields are a major source of methane on a global scale, due to microbial anaerobic decay of organic matter. While uncertainty exists as to the exact contribution to the annual global emissions, they appear to be of the order of 25–170 million metric tonnes or 6–30 percent of annual global methane emissions.

In addition, methane emissions from flooded rice fields may increase by as much as 20 percent in the next decade, since rice production must increase to meet the rice requirements of growing human populations. Rice production is projected to increase from the current level of 458 million tonnes to over 550 million tonnes by the year 2000, and to some 760 million tonnes by the year 2020.

Measures and Policy Options

Reductions in methane emissions from flooded rice fields should be obtained while maintaining the productivity of the rice fields in all instances. In the long run, a comprehensive approach, including management of water systems, cultivar development, efficient fertilizer (both organic and mineral) use, and other management practices could achieve reductions of 10–30 percent. However, current understanding of the complex interaction between methane production and oxidation, and the flux between the atmosphere and the rice fields, is insufficient. This understanding is a prerequisite for determining potential options for reducing methane emissions from flooded rice fields.

Improved understanding of the process contributing to methane emissions from flooded rice fields can only be achieved by integrated, interdisciplinary projects that focus on process-related factors and that will allow for valid extrapolation. Research is needed on the following aspects:

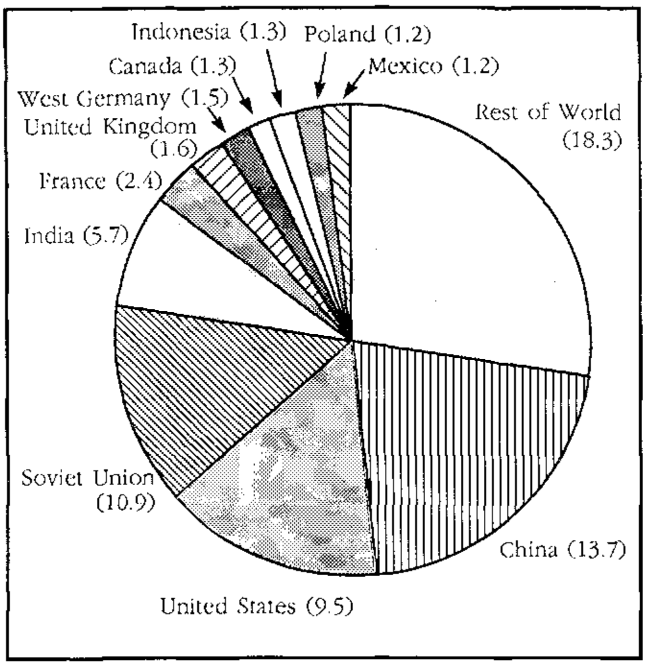
- Biogeochemistry of methanogenesis in flooded rice fields including methane production, methane oxidation, and methanogenesis regulation factors.
- Factors affecting methane fluxes from flooded rice fields, such as climate, soil and water, cultivars, fertilizer application, and cultural practices and variations in fluxes spatially, seasonally, and diurnally.
- Effects of techniques to reduce methane emissions of nitrous oxide.
- Field level measurement techniques to assess spatial variability, and simulation models to synthesize the process and field level data. Technologies and practices for reducing emissions from flooded rice fields need to be developed, demonstrated and assessed, including an evaluation of the costs and benefits. Furthermore, to realize the full potential of the research, existing and possible agricultural policies regarding rice production need to be examined.

4.3.4.2 *The Role of Managed Livestock in the Global Methane Budget*

Ruminant animals produce methane as part of the digestive process. Total methane emission from the digestive processes of domestic ruminant animals have been estimated to be between 60 and 100 million metric tonnes per year, accounting for about 15 percent of the global methane emissions, second only to flooded rice field systems. These estimates suffer from several notable uncertainties that may cause overestimated emissions in some areas and underestimates in others, resulting in an overall underestimation of methane emissions, possibly by large amounts.

In addition, animal wastes from all sources are another potentially large source of methane emissions. Under anaerobic waste management systems (animal wastes under aerobic conditions do not produce methane), uncontrolled methane emissions from cattle wastes are likely to be of the same magnitude as methane emissions from the livestock di-

FIGURE 4.8: Nitrogen Fertilizer Consumption, 1984–1985 (Million Metric Tonnes Nitrogen)



Distribution of the total agricultural fertilizer consumption of 70.5 million tonnes in China, the United States, and the Soviet Union together accounted for just over 50 percent of the 1984/1985 global fertilizer consumption. Currently 5–35 percent of the total anthropogenic N_2O emissions are attributed to agricultural fertilizer consumption.

Source: FAO, 1987.

gestive process. Preliminary analyses indicate that emissions from the source may currently be of the order of 65–100 million tonnes globally or about 15 percent of the methane from livestock digestive processes. Emission estimates from livestock systems should be refined, particularly in areas where interventions and methane control are most likely to be cost effective.

Measures and Policy Options

Reducing emissions from livestock is a particularly attractive methane reduction option because it is usually accompanied by improved animal productivity. While there are considerable differences in feed conversion efficiency between extensively and intensively managed animals, several techniques are available that might reduce emissions per unit of product (e.g., per kilo of meat or liter of milk) by up to 25–75 percent. However, the reductions actually achieved will of course depend on the extent to which and how effectively the appropriate technologies can be deployed. Furthermore, it is recognized that emission reductions achievable with the best technologies and their socio-economic consequences will vary within and among countries with variations in animal, management, and feeding characteristics.

Near-Term Options

Technologies available in the near term are:

- Animal wastes. Indications are that methane recovery through management of animal wastes can be economic in its own right under certain conditions.
- Supplemental feeding practices. Methane emissions can be substantially reduced (perhaps by 60 percent) from livestock on poor diets by strategic supplementation with locally produced feed additives. Experience in India indicates that the supplementation system can be self-sustaining and economic investment.
- Productive enhancing agents. Current economic evaluations indicate that the use of bovine somatotropin (BST) could improve feed conversion efficiency and is economically feasible at this time, taking into account human concerns on the use of BST.

While currently available, these technologies and practices must be further developed, demonstrated, and assessed in terms of the full range of cost reductions, other potential benefits and risks.

Longer-Term Options

Additional avenues exist for methane reduction in the longer term:

- Strategic supplementation of extensively managed cattle. Pastoral cattle management can result in relatively low animal productivity in some cases. Providing strategic supplementation of nutrients to these animals could reduce methane emissions by increasing efficiency and productivity per animal and achieving production targets with smaller herds.

- Diet modification for intensively managed animals. Current research indicates that methane emissions vary under different diets. Increasing the intake of animals and modifying the composition of their diet can reduce emissions per unit of product. Other feed inputs such as whole cotton seeds or polyunsaturated fats also appear to have promising impacts on methane emissions levels. Modifying feeding practices could potentially reduce methane emissions by large amounts in certain circumstances. However, size and location of animal populations for which this is a promising alternative must be identified.
- Reduction of protozoa. Recent studies indicate that reduced protozoa in ruminant digestive systems results in lower methane emissions and may enhance animal productivity. Further promising avenues consist of improvements in reproductive efficiency, which lead to smaller brood herd requirements and microbiological approaches to improved digestion processes. Again, these technologies and practices must be further developed, demonstrated, and assessed in terms of costs, reductions, and other potential benefits. Also, techniques for field level measurements of methane from livestock need to be developed and standardized.

4.3.4.3 *Greenhouse Gas Emissions from Tropical Agriculture*

Sources

Tropical agricultural systems include traditional fallow-cropping system, conventional high-production systems, agroforestry systems, and agropastoral systems.

An assortment of agriculture activities contribute to greenhouse gas emissions in the tropics. Tropical flooded rice fields and cattle are major sources of these gases.

The remainder of tropical emissions are due primarily to biomass burning, either to convert forest and savanna ecosystems into arable land or pastures, to return nutrients to the soil, to reduce shrubs on rotational fallow lands, or to remove crop residues. In all instances associated with biomass burning, emissions of greenhouse gases are not well estimated and no consistent measurement techniques are now in use. Furthermore, no estimates have separated temperate from tropical sources. Initial estimates put total nitrous oxide emissions at 5–15 percent of global emissions; contributions of CO_2 are estimated at 20–40 percent of global emissions, and contributions of NO_x at 10–35 percent of global emissions. Agriculturally related emissions of methane are perhaps best characterized and estimated. They are dominated by rice and livestock production, with a potentially large, but uncertain percentage from biomass burning. Methane contributions from burning are estimated at 20–80 million tonnes per year, or 5–13 percent of the total methane emissions. There is less certainty regarding the emission of carbon dioxide from agriculture, and the relative contribution of each of the major sources: land-use conversion, biomass burning, and soil degradation. The greatest uncertainties are in the area of nitrous oxide emissions, although initial estimates are of 5–15 percent of the global total.

Measures and Policy Options

Policy options must have value to the farmer beyond the greenhouse-gas-reducing benefits. Policies must not hamper national food security goals or distort competition on the world market. The pressure to convert land to crop and pasture use needs to be reduced, thus reducing emissions from burning, soil exposure, and erosion. Increasing the productivity of croplands on suitable soils using appropriate agricultural practices will have that effect. Reclaiming and restoring degraded agricultural lands should also be explored, in addition to enhancing the indigenous uses of native forests and establishing forest cropping systems that reduce the demand for further deforestation. Policies that increase efficiency in the use of water, fertilizer, and crop residues as well as the use of nitrogen-fixing crops should also be pursued. Incentives may be useful in encouraging the use of improved fertilizers and in abandoning the use of mechanized deforestation. Land-tenure policies need to be evaluated to provide an incentive to limit the conversion of moist forest ecosystems to agricultural ecosystems. Education programmes that teach improved organic-residue management and provide an understanding about the consequences of soil degradation need to be developed and proliferated. Some options for reducing greenhouse gas emissions include:

- Conversion of forest land to agricultural, as widely practiced in the tropics, may be reduced by adopting sustainable agricultural practices that optimize yields, or by adopting intensive practices on suitable agricultural soils.
- Reduction of emissions from burning crop residues and the routine burning of savannas through sustainable agriculture, including use of chemical and organic amendments, and improved forage species and management systems.
- Enhancement of soil-carbon storage by the use of different vegetation covers and cropping systems, including agroforestry systems. Agroforestry systems may also increase above-ground carbon storage, in addition to stabilizing soil and providing firewood.
- Limitation of fertilizer-derived emissions of nitrous oxide by use of fertilizers with slower conversion rates that are more in accord with crop requirements or that have been technically engineered to conform to rates of plant uptake. Improving fertilizer application for crops and adoption of alternative agricultural systems, such as agroforestry, also have some promise in this regard. Collaborative research among scientists in developing countries is needed to ensure consideration for regional and local physical and cultural factors, with special focus on carbon and nitrogen cycling, burning practices, and soils.

In addition, research is required in the following areas:

- Nitrous oxide emissions from fertilizer and leguminous crops across a broad range of cropping systems.
- Remote-sensing and monitoring methodology development is needed to evaluate the effects of policies to reduce these practices.
- Better estimates are needed on amounts of biomass burned annually, instantaneous emissions from the fire front, and longer-term biogenic emissions from a burn.
- Improved efficiency of technologies and devices for broadcast burning, charcoaling, and use of fuelwood for heating and cooking. These devices and technologies need to be practical and affordable to indigenous populations.
- Appropriate tree species for agroforestry by sites and regions, and the effects of these trees on soils and cropping systems.
- Potential sinks for greenhouse gases in agricultural systems of the tropics and the interactions between sources and sinks. Long-term studies are needed to quantify the effects of different agricultural management systems on these sinks and especially on soil properties.

4.3.4.4 *Greenhouse Gas Emissions from Temperate/Boreal Agriculture*

Sources

An assortment of agricultural activities contribute to emissions of nitrous oxide, carbon dioxide, and methane in temperate and boreal regions.

Nitrous oxide emissions are estimated at 10–100 kg N/ha/yr globally. These emissions probably result from the significant amounts of nitrogen (of the order of 15–20 percent) that are lost from annual agricultural budgets and cannot be accounted for. In addition, agriculturally derived nitrogen converts to nitrous oxide off-site in water and eroded soil, and is carried in some cases by the movement of fertilizer and inorganic particles from newly converted lands. A significant factor in nitrous oxide emissions is the application of excess fertilizer when it cannot be fully utilized by growing plants, usually due to attempts to minimize uncertainty about crop yields. Nitrogen formulation, placement, and depth are important factors that influence the rate of nitrous oxide emissions, and their effects vary with fertilizer type, soil chemistry, and physical soil conditions. In addition, nitrous oxide emissions could potentially increase in far northern soils near the permafrost belt that now have low levels of denitrification if temperature and moisture regimes shift northward, and if cultivation increases.

Carbon dioxide fluxes are well-known processes, and the soil carbon relationships with crops and permanent vegetation have been modeled fairly well. No-till practice should show a marginal increase in soil carbon, though there is great uncertainty in the soil-carbon relationships involved in tillage practices and residue management. In temperate and boreal agricultural systems, soil carbon can usually be increased or decreased by about 20 percent from the existing continuous arable state when large amounts of organic matter are not added; thus these agricultural soils are not a significant carbon sink. Furthermore, cutbacks in nitrogen inputs from any source may reduce biomass accumulation and annual carbon sequestration. Use of crop rotation with organic matter amendments can increase or maintain soil equilibrium levels of organic carbon. However, in temperate and boreal agricultural systems the effect is very small relative to that which takes place in the conversion to grassland or forest ecosystems. An estimated 25 percent of the global soil carbon is contained in boreal forest soils, and significant amounts of this carbon will be lost if the lands overlying these soils are converted to agricultural use. In addition, drainage of peat bogs and boreal muskegs would release more nitrous oxides and carbon dioxide as water tables drop, while maintaining high water tables in these systems would release more methane.

The total energy demand of intensive systems contributes 3 percent of total anthropogenic carbon dioxide emissions. While significant changes in the energy demands of current agricultural systems are not expected, some marginal contributions to greenhouse gas stabilization may be realized with shifts from conventional tillage to conservation, and partial replacement of chemical fertilizer and pesticides with leguminous crops and biological control systems.

Methane fluxes in boreal and temperate systems do not appear to contribute significantly to current emissions, although these processes are not well known. Uncertainty exists as to whether agricultural soils serve as a sink for methane.

Measures and Policy Options

Agricultural policy formulation should include limitation and mitigation of greenhouse gas emissions. Two options are currently available for reducing emissions of nitrous oxide.

- Improved biological-utilization efficiency in fertilizer use. Farmers may be advised about concepts of nutrient balance with clear definitions about marginal and acceptable losses of nutrients, integrated with tillage and application requirements.
- Market and regulatory strategies. Allowable limits may be established for nitrous oxides and nitrate inputs and losses based on best available information, with the possible utilization of the concept of exchangeable loss units. Nutrient-sensitive areas may be designated such as the Chesapeake Bay area of the United States, where special sets of balance mechanisms must be developed. Also, the concept of stocking rates (in terms of intensity or capacity of the soils resource) may be utilized within intensive agricultural zones, using the capability-rating systems of worldwide soil surveys.

Research is needed on:

- Measurements of nitrogen and nitrous oxide emissions to determine: contributions of nitrates in ground water; the contribution of different legumes, the nitrification and denitrification processes, and the vadose zone; the contribution of arable lands to oxide production in surface waters and sediments; sources such as chemical nitrogen sources, livestock-manure sources, losses from storage, losses from sewage sludge, and losses in animal digestion; and the contribution from different regions of the world.
- Relationship of carbon-nitrogen ratios to gas emissions and factors affecting nitrous oxide-nitrogen ratios during denitrification.
- Mechanisms for reducing gas emissions while maintaining production levels, including optimal chemiforms of nitrogen to meet site-specific characteristics.
- The role of soil as a sink for nitrous oxides.
- Measurement technologies, including scale-dependent micrometeorological methods that are terrain transportable with fast-response sensors, landscape- and regional-scale extrapolation methods, improved nitrate nitrogen tests, and development of integrated data systems to integrate laboratory, field regional, and global scales.

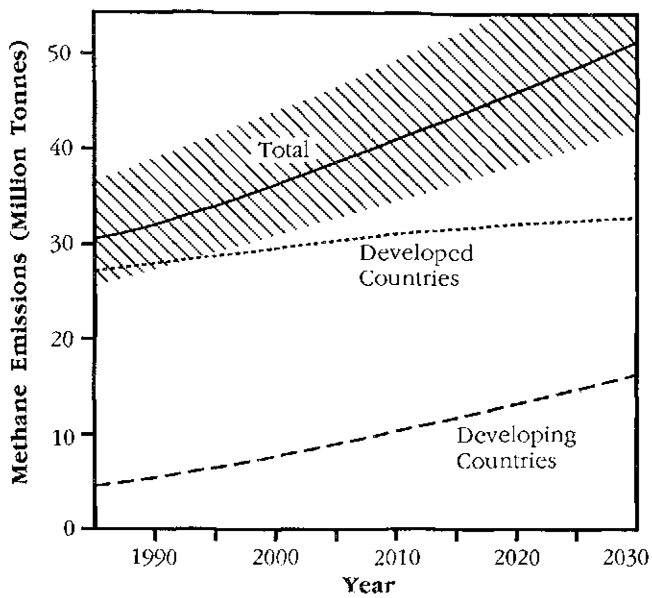
The effectiveness of agricultural-management practice will have to be assessed in terms of emissions reductions, costs, and other benefits. In addition, policy research is needed to evaluate commodity-support programs and their impacts on gas emissions, including the impacts of set-aside policies on the intensive use of remaining lands.

4.4 METHANE FROM LANDFILL SITES AND WASTEWATER TREATMENT PLANTS

4.4.1 EMISSIONS

Organic matter in waste and wastewater is converted into methane by different types of methane bacteria under anaerobic conditions. Anaerobic conditions exist in most landfill sites and in most lagoons used for treating organic loaded wastewater. To estimate global methane production from landfill sites, the following assumptions have been used: Specific waste generation in developed countries is approximately 1 kg per capita per day, and in developing countries it is approximately 0.5 kg per capita and day. Methane generation in developed countries is estimated to be 86 kg methane per metric tonne of waste, and in developing countries 21.5 kg per tonne of waste. Disposal of domestic and commercial waste on landfill sites takes place mainly in urban centers. In rural areas, particularly in developing countries, waste disposal does not take place on large centralized landfills with anaerobic conditions. In order to estimate future emissions, UN statistics were used for urban populations. It is also assumed that for the period up to 2030, no changes take place in waste composition, generation per person and waste treatment. Figure 4.9 shows the estimated increase of methane emissions between the years 1985 and 2030.

FIGURE 4.9: Methane Emissions from Landfill Sites in Developed and Developing Countries, 1985–2030



Note: Cross-hatched area indicates range of uncertainty.

Wastewater treatment plants in developed countries are not considered major sources of methane emissions because aerobic sewage treatment prevails and sludge digesters are equipped with gas-utilization facilities. In most developing countries, where land is comparatively cheap, domestic and industrial wastewater is normally treated in lagoons/oxidation ponds. As a general rule, the first ponds rely on anaerobic conditions, and up to 80 percent of the organic load is digested by methane bacteria in the following 5–15 ponds where oxidation processes take place.

An inventory of methane emissions from wastewater lagoons in the Kingdom of Thailand estimated that 0.5 million tonnes of methane are emitted per year. Little data is available for other countries with comparable conditions. On the basis of the Thai data, the global methane emissions from wastewater lagoons may be estimated to be roughly 20–25 million tonnes per year.

Total global methane emissions from waste disposals and from wastewater lagoons are estimated to be 55–60 million tonnes per year. This is 15 percent of the total methane emissions caused by human activities.

4.4.2 MEASURES AND POLICY OPTIONS

There are a number of technological options for reducing methane emissions from these sources.

Landfill Sites

- Collect and recycle waste paper separately in order to reduce organic matter in wastes.
- Collect and compost vegetable wastes separately in order to reduce organic matter in wastes.
- Utilize aerobic waste treatment (composting), especially in regions with a demand for soil conditioners.
- Utilize landfill gas collection system. It is estimated that 30–90 percent of landfill gas can be recovered by gas collection systems (built-in pipes and wells). The gas can either be burned in torches or be used as an energy source (heating, electricity production). Implementation of gas collection systems in landfill sites is recommended in developed countries. In developing countries, gas-collection systems are reasonable only in cases where methane contents in landfill gas are high enough to justify the high costs of the system.
- Replace landfills with solid waste incineration in developed countries. (Emissions—CO_2-equivalent—from landfills without gas collection are estimated to be 3–5 times higher than from waste incineration).

Wastewater Treatment

Most factories in the agricultural sector have both extremely loaded sewage and high energy demand (steam, electricity). Pretreatment of the sewage in biogas plants could therefore be recommended to reduce methane emission. By replacing bunker oil with methane, a capital return may be reached in about five years.

4.4.3 Costs

The costs of landfill gas collection systems vary among countries and from site to site.

The figures in Table 4.9 give a rough estimation of cost.

TABLE 4.9

Country	US $ per Tonne of Waste	US $ per Tonne of Methane
UK	0.6	10–12
FRG	1–2	15–20
USA	1	10–25

The costs of wastewater pretreatment (biogasplants) mainly depend on type and organic load of the wastewater. Costs per cubic meter reactor volume: U.S.$250–400.

Note: Required reactor volume: 3–7 times the daily wastewater quantity.

4.4.4 Recommendations

- Landfill gas collection systems and flaring appear to be practical for many developed countries and should be considered a near-term option to reduce methane emissions. Additional demonstrations of alternative electrical generation systems could further reduce their costs.
- Biogas systems for wastewater treatment represent an inexpensive source of energy. These systems also reduce water pollution and agricultural waste disposal problems. It is recommended as a short-term option to introduce these systems in developed countries.
- Application of these systems in developing countries requires additional demonstration, training, and technology transfer and it would be a somewhat longer term policy option for these countries.

4.5 DISCUSSION AND CONCLUSIONS

4.5.1 General Issues Affecting the Agriculture, Forestry, and Waste Management Sectors

- Emissions from these sectors are intimately related to the ability of countries to provide for national and global food security and raw materials for export. Policies for emission control therefore may affect the economic basis of some countries, especially developing countries. Efforts to prevent deforestation and to promote afforestation will have multiple impacts that in many cases may enhance the abilities of indigenous agricultural communities to feed themselves and to earn a living from local surplus. Flexibility should be provided to governments to develop least-cost implementation strategies, and countries should pursue those options that increase productivity, make economic sense, and are beneficial for other reasons.

- Agriculture and forestry sources of greenhouse gas emissions consist of very large numbers of small sources, and/or of diffuse sources from large land areas, and as such represent a major challenge.
- To meet this challenge it is desirable to consider a range of measures in the context of a comprehensive response strategy. Currently available options in the sectors are likely to be only partially effective unless coupled with action to reduce emissions from the energy and industry sector.
- Controls on existing sources of pollution which may affect agricultural and forestry lands are an important component in reducing emissions and protecting sinks. Measures to prevent land degradation, hydrological problems and loss of biodiversity, and to improve productivity will generally complement efforts in this sector. Furthermore, analysis is needed about the costs and benefits of individual policy measures.
- There is an urgent need to improve all relevant data, especially on deforestation rates and on the socio-economic factors that lead to the use of deleterious practices in agriculture and forestry. In order to achieve the full potential of identified measures, research is needed into the routes by which new technologies can be introduced while preserving and enhancing social and economic development.
- In the past, the agriculture and forestry sector has proved efficient at introducing new methods of production, not always with beneficial environmental consequences. The pace of technological development (even in the absence of global warming) is likely to remain high in this sector for the foreseeable future. This may afford new opportunities for emission reduction, provided that efficient transfer of knowledge, advice, and technology occur.
- A number of technical options have been identified that could reduce emissions from and enhance sinks in forestry and agriculture, as well as reduce emissions from waste and wastewater treatment. In many cases, their application will require further research and development and large scale education and technology transfer programmes. In this regard, the papers produced by Working Group III on Legal and Institutional Measures, Public Information and Education, Technology Development and Transfer, Financial Measures and Economic Measures are particularly pertinent to developing recommendations for the implementation measures to meet these objectives.

4.5.2 Information on Emission Sources

- Emissions of greenhouse gases, based on the best available estimates, are presented in Table 4.1. Large margins of uncertainty remain in these figures. Many are scaled up from regional estimates which may be unrepresentative at a global level.
- The figures indicate that agriculture and forestry contribute significant amounts of greenhouse gases. Where carbon dioxide is concerned, deforestation, especially in the tropics, is the major concern at present. Agriculture contributes significantly to global methane. Furthermore, the degradation of soil organic matter may release CO_2.
- These emissions are likely to increase over the next few decades, due to population and economic growth, the associated expansion and intensification of agriculture, increased demands on wood, especially for fuel, and pressure to use forestry land for agriculture.

4.5.3 Research

Clearly, there is a need for research to improve emission estimates, and, particularly, to develop standardized methods for measuring emissions at field, regional and global scales. Developing regional budgets that can be related to global scale events is a challenge. Research is also needed into biological processes contributing to emissions and sinks. Development of additional methods for sustainable agriculture and forestry is a priority.

4.5.4 POLICY OBJECTIVES

Nonetheless, policies must be developed not only for the long term, but also to initiate immediate actions to prevent further deterioration. It is necessary to be clear about the strategic objectives of such policies to reduce greenhouse gas emissions from forestry, agriculture, and wastes, and to maintain and provide sinks especially for CO_2:

Forestry

- To reduce the scale of destructive deforestation.
- To promote reforestation and afforestation.
- To promote sustainable forest management.
- To promote more complete utilization of forest products, including recycling.

Agriculture

- To reduce methane emissions from ruminants and rice cultivation.
- To reduce nitrogen loss from cultivation, especially in the form of nitrous oxide.

Wastes and Wastewaters

- To promote efficient waste treatment and collection and utilization of gaseous emissions.

4.5.5 CRITERIA FOR THE SELECTION OF POLICY OPTIONS

It is important that these objectives be met without major economic and social disruption, especially to developing countries. Policies must therefore:

- be of widespread applicability;
- be economic—that is, be compatible with the social and economic life of the communities dependent on agriculture and forestry;
- be equitable in the distribution of the burdens of action between developed and developing countries taking into account the special situation of the latter;
- result in the spread of knowledge, management skills, and technologies;
- result in net environmental gain; and
- take account of the fact that emissions in this sector largely comprise many small sources or diffuse sources from large areas.

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APPENDIX 4.1

DEFORESTATION OF ALL TROPICAL FORESTS, 1980–2050: TWO BASE CASE PROJECTIONS OF INCREASING CARBON EMISSIONS AND TWO POLICY OPTION CASES FOR DECREASING CARBON EMISSIONS

	POLICY OPTION CASES		BASE CASES	
YEAR	LOW	HIGH	LOW	HIGH
1980	.544	.797	.85	2.52
Latin America	.223 (41%)	.320 (43%)	.409 (48%)	1.037 (41%)
Africa	.174 (32%)	.235 (29%)	.204 (24%)	.584 (23%)
Asia	.147 (27%)	.220 (27%)	.237 (28%)	.898 (36%)
2000	.387	.668	.96	2.91
Latin America	.150 (39%)	.294 (44%)	.463 (48%)	1.432 (49%)
Africa	.133 (34%)	.201 (30%)	.229 (23%)	.803 (28%)
Asia	.104 (27%)	.173 (26%)	.268 (28%)	.674 (23%)
2020	.221	.530	1.05	3.89
Latin America	.053 (24%)	.202 (38%)	.509 (48%)	1.887 (48%)
Africa	.104 (47%)	.168 (32%)	.245 (23%)	1.054 (27%)
Asia	.065 (29%)	.160 (30%)	.295 (28%)	.948 (24%)
2050			1.18	4.99
Latin America			.576 (49%)	2.289 (46%)
Africa			.269 (23%)	1.389 (28%)
Asia			.335 (28%)	1.311 (26%)

Policy Option Cases (Grainger, 1989a): Decreased forestation and emissions are expected to result from increases in agricultural productivity that relieve pressure to clear new land. Increases in productivity are adjusted for changes in per capita consumption for a net gain. In the high case, net agricultural productivity per ha rises by 0.5%, 0.0% and 0.5% per year for Africa, Asia-Pacific and Latin America respectively; and by 1.0%, 0.0% and 1.0% per year respectively, in low case scenario. Biomass estimates are the same in both cases, based on "volume over bark" estimates FAO (1981) and procedures of Brown and Lugo (1984).

Base Cases (Houghton, 1990b): Increased deforestation is forecast. The low base case assumes low forest biomass estimates (roughly) comparable to Grainger's biomass assumptions) and linear increases in the rate of deforestation. The high base case assumes high forest biomass and population based deforestation rates. The biomass estimates are outlined in Houghton et al., 1985.

APPENDIX 4.2

Low and High Base Case Carbon Emissions Projections on a Country-by-Country Basis for Deforestation of All Tropical Forest for 1980–2050

(in Billion Tonnes of Carbon per Year)

LOW BASE CASE

Net Flux from Linear Rates of Forest Conversion and Low Forest Biomass Estimates

Countries by Global Region	1980	2000	2025	2050
TROPICAL AMERICA				
Belize	0.3	0.3	0.4	0.4
Bolivia	3.3	3.8	4.3	4.7
Brazil	174.7	198.0	223.6	249.2
Colombia	61.2	69.4	78.4	87.4
Costa Rica	4.6	5.2	5.9	6.6
Cuba	0.1	0.1	0.1	0.1
Dominican Republic	0.1	0.1	0.1	0.1
Ecuador	19.7	22.3	25.2	28.1
El Salvador	0.1	0.2	0.2	0.2
French Guiana	0.2	0.2	0.3	0.3
Guatemala	4.9	5.5	6.3	7.0
Guyana	0.3	0.3	0.4	0.4
Haiti	0.1	0.1	0.1	0.1
Honduras	5.0	5.7	6.4	7.2
Jamaica	0.1	0.1	0.1	0.1
Mexico	23.7	26.9	30.4	33.8
Nicaragua	8.4	9.5	10.7	11.9
Panama (Not Canal Zone)	2.7	3.0	3.4	3.8
Paraguay	5.9	6.7	7.6	8.5
Peru	22.2	25.2	28.5	31.7

APPENDIX 4.2 (*continued*): LOW BASE CASE

COUNTRIES BY GLOBAL REGION	1980	2000	2025	2050
Suriname	0.3	0.3	0.4	0.4
Trinidad & Tobago	0.1	0.1	0.1	0.1
Venezuela	12.7	14.4	16.2	18.1
FAR EAST				
Bangladesh	0.5	0.6	0.6	0.7
Bhutan	0.2	0.2	0.3	0.3
Brunei	1.9	2.2	2.4	2.7
Burma	13.4	15.2	17.1	19.1
Democratic Kampuchea	3.4	3.9	4.4	4.8
Sri Lanka	1.2	1.4	1.5	1.7
India	8.7	9.9	11.1	12.4
Indonesia (& East Timor)	51.1	57.9	65.4	72.9
Lao People's Democ. Rep.	23.6	26.8	30.3	33.7
Malaysia	35.4	40.0	45.3	50.3
Pakistan	0.8	0.9	1.0	1.1
Thailand	27.2	30.8	34.8	38.8
Nepal	4.9	5.5	6.3	7.0
Philippines	14.9	16.9	19.0	21.2
Viet Nam	9.4	10.7	12.1	13.4
Papua New Guinea	2.5	2.8	3.2	3.5
AFRICA				
Algeria				
Angola	3.9	4.4	5.0	5.6
Burundi				
United Rep. of Cameroon	11.0	12.5	14.1	15.8
Central African Rep.	2.5	2.9	3.3	3.6
Chad	3.0	3.4	3.8	4.2
Congo	2.4	2.7	3.1	3.4
Equatorial Guinea	0.2	0.2	0.3	0.3
Benin	1.7	1.9	2.2	2.4
Mali	1.5	1.7	1.9	2.1
United Rep. of Tanzania	3.5	3.9	4.4	4.9
Burkina Faso	3.0	3.4	3.8	4.2
Mozambique	5.0	5.6	6.3	7.1
Niger	1.1	1.3	1.5	1.6
Nigeria	23.4	26.5	29.9	33.3

APPENDIX 4.2 (*continued*): LOW BASE CASE

COUNTRIES BY GLOBAL REGION	1980	2000	2025	2050
Guinea Bissau	1.8	2.1	2.4	2.6
Rwanda	0.2	0.2	0.3	0.3
Uganda	1.6	1.8	2.0	2.2
Zambia	3.0	3.4	3.8	4.2
Botswana	0.5	0.6	0.6	0.7
Liberia	2.9	3.3	3.7	4.1
Namibia	0.7	0.8	0.9	1.0
Ethiopia	5.5	6.3	7.1	7.9
Gambia	0.1	0.2	0.2	0.2
Ghana	3.8	4.3	4.8	5.4
Guinea	3.9	4.4	5.0	5.6
Kenya	1.2	1.4	1.5	1.7
Malawi	11.1	12.6	14.2	15.9
Sierra Leone	0.4	0.4	0.5	0.5
Côte d'Ivoire (Ivory Coast)	41.4	46.9	53.0	59.1
Madagascar	8.7	9.9	11.1	12.4
Togo	0.4	0.4	0.5	0.5
Senegal	2.1	2.3	2.6	2.9
Somalia	0.8	0.9	1.0	1.1
Zimbabwe	3.0	3.4	3.8	4.2
Gabon	1.6	1.8	2.0	2.2
Sudan	18.8	21.3	24.1	26.9
Zaire	24.8	28.1	31.7	35.4
TROPICS TOTAL	**750.0**	**850.0**	**960.0**	**1070.0**
TROPICAL AMERICA	**350.6**	**397.4**	**448.8**	**500.2**
TROPICAL ASIA	**199.0**	**225.6**	**254.8**	**284.0**
TROPICAL AFRICA	**200.3**	**227.0**	**256.4**	**285.8**

Note: Totals reflect rounding.

HIGH BASE CASE

NET FLUX FROM POPULATION-BASED RATES OF FOREST CONVERSION AND HIGH FOREST BIOMASS ESTIMATES

COUNTRIES BY GLOBAL REGION	1980	2000	2025	2050
TROPICAL AMERICA				
Belize	0.9	1.1	1.5	1.8
Bolivia	10.3	11.9	17.1	20.5
Brazil	510.5	589.5	844.8	1010.9
Colombia	187.3	216.3	309.9	370.9

APPENDIX 4.2 (*continued*): **HIGH BASE CASE**

COUNTRIES BY GLOBAL REGION	1980	2000	2025	2050
Costa Rica	14.3	16.5	23.6	28.3
Cuba	0.2	0.2	0.3	0.3
Dominican Republic	0.2	0.2	0.3	0.3
Ecuador	60.6	70.0	100.3	120.0
El Salvador	0.3	0.4	0.5	0.6
French Guiana	0.5	0.5	0.8	0.9
Guatemala	15.2	17.5	25.1	30.1
Guyana	0.6	0.7	1.0	1.2
Haiti	0.2	0.2	0.3	0.3
Honduras	15.3	17.7	25.4	30.4
Jamaica	0.2	0.2	0.3	0.3
Mexico	50.7	58.6	84.0	100.5
Nicaragua	25.7	29.6	42.5	50.8
Panama (Not Canal Zone)	8.4	9.6	13.8	16.5
Paraguay	12.8	14.7	21.1	25.3
Peru	68.4	78.9	113.1	135.4
Suriname	0.6	0.7	1.0	1.2
Trinidad & Tobago	0.2	0.2	0.3	0.3
Venezuela	27.2	31.4	45.0	53.8
FAR EAST				
Bangladesh	3.2	3.7	5.3	6.3
Bhutan	0.5	0.5	0.8	0.9
Brunei	4.1	4.7	6.8	8.1
Burma	77.8	89.8	128.7	154.0
Democratic Kampuchea	7.3	8.4	12.1	14.4
Sri Lanka	2.6	3.0	4.3	5.1
India	50.1	57.9	82.9	99.3
Indonesia (& East Timor)	291.5	336.6	482.4	577.2
Lao People's Democ. Rep.	128.7	148.6	212.9	254.8
Malaysia	75.8	87.5	125.3	150.1
Pakistan	1.7	1.9	2.8	3.3
Thailand	143.5	165.8	237.5	284.2
Nepal	10.5	12.1	17.3	20.8
Philippines	86.1	99.5	142.5	170.5
Viet Nam	54.8	63.3	90.7	108.6
Papua New Guinea	5.3	6.1	8.8	10.5

APPENDIX 4.2 (*continued*): HIGH BASE CASE

Countries by Global Region	1980	2000	2025	2050
AFRICA				
Algeria				
Angola	8.4	9.6	13.8	16.5
Burundi				
United Rep. of Cameroon	23.7	27.4	39.2	46.9
Central African Rep.	5.5	6.3	9.0	10.8
Chad	6.4	7.4	10.6	12.6
Congo	5.2	6.0	8.5	10.2
Equatorial Guinea	0.5	0.5	0.8	0.9
Benin	3.8	4.4	6.3	7.5
Mali	3.2	3.7	5.3	6.3
United Rep. of Tanzania	47.4	8.6	12.3	14.7
Burkina Faso	6.4	7.4	10.6	12.6
Mozambique	10.6	12.3	17.6	21.1
Niger	2.4	2.8	4.0	4.8
Nigeria	90.4	104.4	149.6	179.0
Guinea Bissau	4.6	5.3	7.5	9.0
Rwanda	0.5	0.5	0.8	0.9
Uganda	3.3	3.9	5.5	6.6
Zambia	6.4	7.4	10.6	12.6
Botswana	1.1	1.2	1.8	2.1
Liberia	11.8	13.7	19.6	23.5
Namibia	1.5	1.8	2.5	3.0
Ethiopia	11.8	13.7	19.6	23.5
Gambia	0.3	0.4	0.5	0.6
Ghana	11.7	13.5	19.4	23.2
Guinea	13.4	15.4	22.1	26.5
Kenya	2.6	3.0	4.3	5.1
Malawi	23.8	27.5	39.5	47.2
Sierra Leone	1.5	1.8	2.5	3.0
Côte d'Ivoire (Ivory Coast)	152.7	176.3	252.6	302.3
Madagascar	35.2	40.7	58.3	69.8
Togo	1.1	1.2	1.8	2.1
Senegal	4.4	5.1	7.3	8.7
Somalia	1.5	1.8	2.5	3.0
Zimbabwe	6.4	7.4	10.6	12.6

APPENDIX 4.2 (*continued*): HIGH BASE CASE

Countries by Global Region	1980	2000	2025	2050
Gabon	3.3	3.9	5.5	6.6
Sudan	40.4	46.7	66.9	80.0
Zaire	53.2	61.4	88.0	105.3
TROPICS TOTAL	**2520.0**	**2910.0**	**4170.0**	**4990.0**
TROPICAL AMERICA	**1010.3**	**1166.6**	**1671.8**	**2000.5**
TROPICAL ASIA	**943.4**	**1089.5**	**1561.2**	**1868.2**
TROPICAL AFRICA	**566.3**	**653.9**	**937.1**	**1121.3**

Note: Totals reflect rounding.

These low and high base case projections represent the upper and lower bounds for the range in emissions possible in models of linear, exponential, and population based deforestation rates, run with both high and low forest biomass estimates. The low base case uses linear deforestation rates reported by FAO/UNEP (1981) for the years 1975–85, coupled with low forest biomass estimates. The high base case uses rates of deforestation that are a function of rates of population growth, coupled with high forest biomass estimates.

Estimates of flux are given for 1980, 2000, 2025, and 2050. After 2050, country-by-country estimates are especially dangerous for the reasons given below. Estimates for the year 2025 in this Appendix (instead of 2020) were selected so they would be directly comparable with the EIS data. They are, however, basically interchangeable with the estimates for 2020 in Appendix 4.1 and Figure 4.2 of this report given the error factor involved in making such projections. The low base case emissions estimates are slightly lower in this Appendix than in Appendix 4.1 and Figure 4.2 due to subsequent refinements in the accuracy of the model.

Two important qualifications should be recognized for these projections:

1) The projections were based on rates of deforestation for *entire regions*, not countries. Thus, projected fluxes drop to zero only when the forests of an entire region are gone. In fact, some countries will eliminate their forests before others, and fluxes there will drop to zero before all forests in the region are gone. If the projections were carried out country-by-country, the estimates of flux, for countries as well as regions, would probably be lower.
2) All estimates of flux are based on extrapolations or functions of FAO/UNEP data that are now more than ten years old. It is, therefore, interesting to compare these projections with estimates of flux from Myers' new rates of deforestation. Such a comparison can be done for closed forests only, but if Myers' recent estimates are correct, all the projections are low.

1990 Fluxes of Carbon from Deforestation of Closed Forests Only

Linear		Population		Myers' Recent Estimate
Low	High	Low	High	
0.80	1.58	0.85	1.68	0.9 to 2.3

Source: Houghton, 1990b