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This research project was carried out on the basis of a contract between the European Parliament, Directorate General for Research and Integrated Environmental Management (IEM), situated in Athens Greece, in order to supply services to the Scientific and Technological Options Assessment Programme (STOA) of the European Parliament.

The purpose of this study was to examine the impacts of Climate Change on Agricultural Production and to propose measures and initiatives on behalf of the European Parliament in the framework of the European Union Agricultural Policy.

This study was carried out by a group of experts who collected information on the project, from relevant sources.

The report is accompanied by an Executive Summary, Conclusions and Bibliography.

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ABSTRACT

Climate plays a major role in determining the yield levels, the year-to-year variability and the spatial patterns of global agriculture. Agriculture is sensitive to short term changes in weather and to seasonal, annual and longer term variations in climate. Over the long term, agriculture is able to tolerate moderate variations about the climatic mean. Longterm marked changes in temperature, precipitation, and solar radiation will have an effect on the productivity of crop and livestock agriculture. Climate change will also have economic effects on agriculture, including changes in farm profitability, prices, supply, demand, trade, and regional comparative advantages. The magnitude and geographical distribution of such climate-induced changes may affect our ability to expand food production as required to feed a population of more than 10000 million people projected for the middle of the next century. Climate change could thus have far-reaching effects on patterns of trade among nations, development, and food security. The world's forest estate has declined significantly in both area and quality in recent decades. The major causes of this decline are deforestation and air pollution, with climate change, storms and fires aggravating the situation.

Because average temperatures are expected to rise more near the north and south poles than near the equator, the shift in climate zones will be more pronounced at higher latitudes. In the mid latitude regions (45^0 to 60^0), present temperature zones could shift by 150-550 km. Since each of today's latitudinal climate belts are optimal for particular crops, such shifts could strongly affect agricultural and livestock production. Efforts to shift crops poleward in response could be limited by the inability of soil types in the new climate zones to support intensive agriculture as practised today in the main producer countries. The impact on crop yields and productivity will vary considerably. Added heat stress, shifting monsoons, and drier soils may reduce yields in the tropics and subtropics, whereas longer growing seasons may boost yields in northern Canada and Europe. Projections of regional climate change and the resulting agricultural impacts, however, are still full of uncertainties.

Even if the Kyoto Protocol is ratified and nations abide by its terms, neither of which can be taken for granted, its effect will only slow - not halt - the build-up of greenhouse gases. Effective policies can help to improve food security. The negative effects of climate change on agriculture can be limited by changes in crops and crop varieties, improved water management and irrigation systems, adapted planting schedules and tillage practices, and better watershed management and land-use planning. In addition to addressing the physiological response of plants and animals, policies can seek to improve how production and distribution systems cope with fluctuations in yields.

EXECUTIVE SUMMARY

Climate plays a major role in determining the yield levels, the year-to-year variability and the spatial patterns of global agriculture. Agriculture is sensitive to short term changes in weather and to seasonal, annual and longer term variations in climate. Over the long term, agriculture is able to tolerate moderate variations about the climatic mean.

Longterm marked changes in temperature, precipitation, and solar radiation will have an effect on the productivity of crop and livestock agriculture. Climate change will also have economic effects on agriculture, including changes in farm profitability, prices, supply, demand, trade, and regional comparative advantages. The magnitude and geographical distribution of such climate-induced changes may affect our ability to expand food production as required to feed a population of more than 10000 million people projected for the middle of the next century. Climate change could thus have far-reaching effects on patterns of trade among nations, development, and food security.

Below are summarised some of the issues and uncertainties surrounding the question of global warming and its effects on agricultural production.

I. **If nothing is done to reduce emissions, current climate models predict a global warming of about 2^0C between 1990 and 2100.** This projection takes into account the effects of aerosols and the delaying effect of the oceans. This oceanic inertia means that the earth's surface and lower atmosphere would continue to warm by a further 1-2^0C even if greenhouse gas concentrations stopped rising in 2100.

II. **The range of uncertainty in this projection is 1^0C to 3.5^0C.** Even a 1^0C rise would be larger than any century-time-scale trend for the past 10,000 years. Uncertainties about future emissions, climate feedbacks, and the size of the ocean delay all contribute to this uncertainty range.

III. **The earth's average sea level is predicted to rise by about 50 cm by 2100.** The uncertainty range is large -15 to 95 cm- and changing ocean currents could cause local and regional sea levels to rise much more or much less than the global average. The main cause of this rise is the thermal expansion of the upper layers of the ocean as they warm, with some contribution from melting glaciers. Slightly faster melting of the Greenland and Antarctica ice sheets is likely to be balanced by increased snowfall in both regions. As the warming penetrates deeper into the oceans and ice continues to melt, sea level will continue rising well after surface temperatures have levelled off.

IV. **Regional and seasonal warming predictions are much more uncertain.** Although most areas are expected to warm, some will warm much more than others. The largest warming is predicted for cold northern regions in winter. The reason is that snow and ice reflect sunlight, so less snow means more heat is absorbed from the sun, which enhances any warming: a strong positive feedback effect. By the year 2100, parts of northern Canada and Siberia are predicted to warm by up to 10^0C in winter, but less than 2^0C in summer.

V. **Inland regions are projected to warm faster than oceans and coastal** zones. The reason is simply the ocean delay, which prevents the sea surface from warming as fast as the land.

VI. **Aerosols may counteract some of the effects of greenhouse warming in the vicinity of major industrialised regions.** Clouds of superfine sulphate particles from burning coal and oil should counteract greenhouse warming over much of the eastern USA, Eastern Europe, and parts of China. But since some action is likely to reduce sulphur emissions because of acid rain, the size of this effect is unpredictable.

VII. **Total precipitation is predicted to increase, but at the local level trends are much less certain.** Winter time precipitation in the far north is likely to rise, but what happens in mid-latitudes and in the tropics depends very much on the details of the particular climate model and the emissions scenario.

Including the effects of aerosols, for example, significantly weakens the Asian summer monsoon in prediction models.

VIII. **More rain and snow will mean wetter soil conditions in high-latitude winters, but higher temperatures may mean drier soils in summer.** Local changes in soil moisture are clearly important for agriculture, but models still find it difficult to simulate them. Even the sign of the global change in summertime soil moisture -whether there will be an increase or a decrease- is uncertain.

IX. **The frequency and intensity of extreme weather events such as storms and hurricanes may change.** However, models still cannot predict how. The models used to simulate climate change cannot themselves simulate extreme weather events, so the evidence is indirect. There is some concern that patterns of extreme weather may change because the models predict changes in ocean surface temperatures and other factors that are known to affect storm and hurricane development. However, it will be many years before scientists can predict whether individual regions will become more or less stormy.

X. **Rapid and unexpected climate transitions cannot be ruled out.** The most dramatic such change, the collapse of the west Antarctic ice sheet, which would lead to a catastrophic rise in sea level, is now considered unlikely in the next 100 years. There is evidence that changes in ocean circulation which have a significant impact on regional climate (such as weakening of the Gulf Stream that warms Europe) can take place in only a few decades. Changes in a number of circulation features, including El Ni;o Southern Oscillation events, mid-latitude Northern Hemisphere westerlies and the location and intensity of the Aleutian low pressure system in the North Pacific, may all be related to increased global warming in the twentieth century . External factors, such as a series of volcanic eruptions or a change in the power output of the sun, could also have a major impact, but the consensus is that climate change over the 21st century as a whole is likely to be dominated by the effects of greenhouse gas emissions.

XI. **Soil moisture will be affected by changing precipitation patterns.** Based on a global warming of 1-3.5^{0}C over the next 100 years, climate models project that both evaporation and precipitation will increase, as will the frequency of intense rainfalls. While some regions may become wetter, in others the net effect of an intensified hydrological cycle will be a loss of soil moisture. Some regions that are already drought-prone may suffer longer and more severe dry-spells. The models also project seasonal shifts in precipitation patterns: soil moisture will decline in some mid-latitude continental regions during the summer, while rain and snow will probably increase at high latitudes during the winter.

XII. **Higher temperatures will influence production patterns.** Plant growth and health may benefit from fewer freezes and chills, but some crops may be damaged by higher temperatures, particularly if combined with water shortages. Certain weeds may expand their range into higher-latitude habitats. There is also some evidence that the poleward expansion of insects and plant diseases will add to the risk of crop loss.

XIII. **More carbon dioxide in the atmosphere could boost productivity.** In principle, higher levels of CO_2 should stimulate photosynthesis in certain plants. This is particularly true for so-called C3 plants because increased carbon dioxide tends to suppress their photo-respiration, making them more water efficient. C3 plants make up the majority of species globally, especially in cooler and wetter habitats, and include most crop species, such as wheat, rice, barley and potato. The response of C4 plants would not be as dramatic. C4 plants include such tropical crops as maize, sugar cane, sorghum and millet, which are important for the food security of many developing countries, as well as pasturage and forage grasses. Experiments based on a doubling of CO_2 concentrations have confirmed that 'CO_2 fertilization' can increase mean yields of C3 crops by 30%. This effect could be enhanced or reduced, however, by accompanying changes in temperature, precipitation, pests, and the availability of nutrients

XIV. **Climate and agricultural zones are likely to shift towards the poles**. Because average temperatures are expected to rise more near the north and south poles than near the equator, the shift in climate zones will be more pronounced at higher latitudes. In the mid latitude regions (45^0 to 60^0), present temperature zones could shift by 150-550 km. Since each of today's latitudinal climate belts are optimal for particular crops, such shifts could strongly affect agricultural and livestock production. Efforts to shift crops poleward in response could be limited by the inability of soil types in the new climate zones to support intensive agriculture as practised today in the main producer countries.

XV. **Some agricultural regions will be threatened by climate change, while others may benefit.** The impact on crop yields and productivity will vary considerably. Added heat stress, shifting monsoons, and drier soils may reduce yields in the tropics and subtropics, whereas longer growing seasons may boost yields in northern Canada and Europe. Projections of regional climate change and the resulting agricultural impacts, however, are still full of uncertainties.

XVI. **Food security risks are primarily local and national**. Studies suggest that global agricultural production could be maintained relative to the expected baseline levels over the next 100 years. However, regional effects would vary widely, and some countries may experience reduced output even if they take measures to adapt. This conclusion takes into account the beneficial effects of CO_2 fertilization but not other possible effects of climate change, including changes in agricultural pests and soils. According to one view, the warming and increased precipitation in the northern latitudes (near 70^0 N) would improve the agricultural prospects in Canada, northern Europe, and the area of the former USSR, whereas the increases in temperature and drying of interiors of continents in the mid-latitudes (near 40^0 N and S) is expected to lead to reductions in agricultural productivity in the United States and western Europe. In southern Europe it is expected that there will be a large decline in summer soil moisture and a major reduction in agricultural potential. Considerable work has been accomplished on agricultural climate change impacts in western Europe. In general, modelling studies have suggested that simulated grain yields are likely to increase in the north, but to decrease in the Mediterranean area even with agronomic adaptations. The zone of maize production may extend as far as north as the UK and central Finland. Vegetable crops may expand in northern and western areas, but decline in southern Europe. Fruit production may experience winter chilling and loss of production in the south, where grapes in particular are likely to be affected. Growing water deficits in southern Europe will intensify the demand for irrigation. Projected coastal inundation of rice growing regions in parts of Southeast Asia, such as Bangladesh, combined with the projected movement of the Asian monsoon away from the Indian sub-continent could lead to reduced agricultural production.

XVIII. **The most vulnerable are the landless, poor and isolated.** Poor terms of trade, weak infrastructure, lack of access to technology and information, and armed conflict will make it more difficult for these people to cope with the agricultural consequences of climate change. Many of the world's poorest areas, dependent on isolated agricultural systems in semi-arid and arid regions, face the greatest risk. Many of these at risk populations live in sub-Saharan Africa; south, east, and southeast Asia; tropical areas of Latin America; and some Pacific island nations.

XVIIII. **The world's forest estate has declined significantly in both area and quality in recent decades**. The major causes of this decline are deforestation and air pollution, with climate change, storms and fires aggravating the situation. Forests typically take centuries to adapt to new conditions and so would be especially hard-hit. Although the enhancement of plant growth and yield in CO_2 enriched environments has been well documented in short term experiments, it still remains unclear whether enhanced atmospheric CO_2 concentrations will continue to stimulate growth and productivity of woody species in the long term (i.e. several years). Increased concentrations of atmospheric CO_2 also result in an increased demand by trees for other resources, such as nutrients. When nutrient supply rates do not meet growth rates, plant nutrient status declines and nutrients become limiting. It is considered that sensitive stages in the life cycle of most tree species - including pollination, flower production, and seed germination- would be upset by climate change.

XIX. In December 1997, representatives of more than 160 nations assembled in Kyoto, Japan, to sign a historic protocol to the 1992 Framework Convention on Climate Change Under the Kyoto Protocol industrialized countries are to reduce their collective emissions of six greenhouse gases legally binding by 5.2% (average) until 2012. Developing countries do not have to cut emissions, but will receive additional financial resources and environmental friendly technology; **Even if the Kyoto Protocol is ratified and nations abide by its terms, neither of which can be taken for granted, its effect will only slow - not halt - the buildup of greenhouse gases.** Unlike the Montreal Protocol on Substances That Deplete the Ozone Layer, which will eventually "solve" the problem of ozone depletion if adhered to, the Kyoto

Protocol will not "solve" the problem of climate change, but only begin the long process of weaning the world away from heavy reliance on fossil fuels and other sources of greenhouse gases. Calculations by the IPCC make it clear that emission reductions well beyond any contemplated in the Kyoto treaty will be needed to stabilize atmospheric CO_2 concentrations at even two or three times their preindustrial level of 280 parts per million. For instance, stabilizing CO_2 concentrations at double their pre-industrial level would require eventually reducing global carbon emissions (from all nations) by 60% from 1990 levels. It has been stated that if industrial countries gained confidence that developing countries would join them in the move away from fossil fuels, they might be more ready to embrace stronger emissions limits. However developing countries can only proceed with that transition if industrial countries are actively commercializing the needed technologies. A global policy and research effort to speed up reforestation, promote soil conservation, and encourage energy conservation to increase the magnitude of the natural sinks for CO_2, and reduce consumption of fossil fuels, would be "no-regret" approaches. (S.H. Wittwer, 1995).

XX. **Forestry and agriculture are important sources of carbon dioxide, methane and nitrous oxide.** The world's forests contain vast quantities of carbon. Some forests act as sinks by absorbing carbon from the air, while forests whose carbon flows are in balance act as reservoirs. At the global level, deforestation and changes in land use make forests a net source of carbon dioxide. As for agriculture, it accounts for about 20% of the human enhanced greenhouse effect. Intensive agricultural practices such as livestock rearing, wet rice cultivation, and fertilizer use emit 50% of human related methane and 70% of our nitrous oxide. Measures and technologies are currently available that could significantly reduce net emissions from both forests and agriculture -and in many cases cut production costs, increase yields, or offer other socio-economic benefits. Forests will need better protection and management if their carbon dioxide emissions are to be reduced; the carbon stored in trees, vegetation, soils, and durable wood products can be maximized; The goal for CO_2 reductions from the agricultural sector should be to make sure that the land is used as efficiently as possible, thereby maximizing the preservation of non-cultivated areas such as forests. Agricultural soils are a net source of carbon dioxide but they could be made into a net sink through reduced tillage; methane emissions from livestock could be cut with new feed mixtures. Waste management practices should strive to ensure aerobic conditions at all times to minimize potential CH_4 releases. Methane from wet rice cultivation can be reduced significantly through the selection and development of cultivars and changes in the nutrient and water management practices; nitrous oxide emissions from agriculture can be minimized by paying closer attention to the use and management of fertilizer techniques.

XXII. **Effective policies can help to improve food security.** The negative effects of climate change can be limited by changes in crops and crop varieties, improved water management and irrigation systems, adapted planting schedules and tillage practices, and better watershed management and land-use planning. In addition to addressing the physiological response of plants and animals, policies can seek to improve how production and distribution systems cope with fluctuations in yields.

Preventive methods of global climate change concerning agriculture are intrinsically linked to methods promoting sustainable cultivation and sustainable forms of agriculture. From the sustainability point of view the agricultural sector has shown some disconcerting developments over the last decades. There is currently the opportunity to make key areas of European Union policy more sustainable. In March 1998 the European Commission adopted legislative proposals for reform of the CAP based on a package of measures entitled Agenda 2000. The policy document Agenda 2000 reflects the rapidly changing context for European agricultural policy, emphasising a welcome shift towards a more quality-oriented agriculture policy and towards consideration of the rural economy as a whole, with emphasis on employment. Although the general direction for change is set by Agenda 2000 and global developments, providing the opportunity for reaching the objectives for sustainable agriculture, many unresolved issues remain to be considered further as reform of the CAP gathers pace. The new CAP will need to be driven by much stronger environmental imperatives. Sustainability will need to be pursued through integration across and within all economic sectors (such as transport, energy and agriculture) and agricultural product markets. Consistency between all policy areas will minimise potential conflicts that may arise from integration. Market conditions will need to be created that enable farmers to promote sustainability while preserving their competitiveness in a global market. Local policy implementation will need to be promoted and diversity of nature and products will need to be preserved across the entire agriculture and food chain in such a way that high standards of environmental protection are achieved. There is a need to recognise and evaluate those environmental and social impacts which are not reflected in the price of goods and services.

The European Commission’s proposed reform of the CAP contains some promising elements, including a shift from price support to direct payments, the possibility for attaching environmental and landscape conditions to payments (“cross compliance”) and the comprehensive approach to rural development. However the most positive measures are voluntary for Member States. A small number of major adaptations could allow a move towards sustainable agriculture. Cross-compliance should be made compulsory for all Member States in a form which ensures environmental progress. Ground rules and guidelines for cross compliance and for codes of good practice should be set at EU level, although setting nature and landscape conditions is best carried out on a national level. The role of rural development should be enlarged and the approach made truly sustainable. The entire CAP reform should be subject to a comprehensive strategic environmental impact assessment (SEA).

In view of the present uncertainties over the pace and magnitude of climate change, the most promising and most cost-effective policy options of agricultural adaptation are ones for which benefits accrue even if no climate change takes place. Small changes can be accommodated in the normal course of development. These would entail relatively little cost and would be incorporated into existing planning mechanisms without major institutional development. Such policy options include liberalization of trade; flexibility of commodity support programmes. dissemination of conservation management practices. Agricultural drought management; promoting efficiency of irrigation and water use; protection of permanently flooded areas; improved short term climate prediction; maintenance of seed banks; new crop varieties and species; different crop varieties or species; investment in agricultural research and infrastructure. In Europe, climate adaptation policies will primarily need to be combined with or added to existing EU agricultural policies and in particular the EU Common Agricultural Policy, in view of the European Commission’s current proposed reform of the CAP.

OPTIONS BRIEF

A global policy and research effort to speed up reforestation, promote soil conservation, and encourage energy conservation through policies such as the removal of energy subsidies and high subsidies for road use; energy and emissions taxes; energy efficiency standards; new incentive mechanisms used to encourage reliance on renewable energy and co-generation, would be "no-regret" approaches. (S.H. Wittwer, 1995).

Preventive methods of global climate change concerning agriculture are intrinsically linked to methods promoting sustainable cultivation and sustainable forms of agriculture. There is currently the opportunity to make key areas of European Union policy more sustainable. In March 1998 the European Commission adopted legislative proposals for reform of the CAP based on a package of measures entitled Agenda 2000. Ongoing discussions on the proposals for reform of the CAP are scheduled to continue up to the first half of 1999.

Five core conclusions can be reached, regarding the policies that will need to be pursued if the shift to sustainable agriculture is to be achieved:

Market conditions will need to be created that enable farmers to promote sustainability while preserving their competitiveness in a global market. Solving such and other potential conflicts will involve the European Union playing a leading role within the World Trade Organisation.

Local policy implementation will need to be promoted and diversity of nature and products will need to be preserved across the entire agriculture and food chain in such a way that high standards of environmental protection are achieved. A balance is required to be achieved between clear strategic objectives set at EU level and implementation devolved from Member States to local communities in order to develop locally appropriate and tailored solutions. Local products grown organically must not be prevented market access due to the fact that their size, form or colour does not meet EU technical standards.

There is a need to recognise and evaluate those environmental and social impacts which are not reflected in the price of goods and services. Policy should take full account of these impacts at the policy, business and individual levels in order to ensure accountability by all stakeholders. Hidden subsidies, for example, should be made transparent and community funds should not support unsustainable practices. Eventually environmental and social impacts should be reflected in the price of goods and services, on the basis of the polluter pays principle, which would in addition allow organically grown produce a more competitive position in the market.

More sophisticated linkages within different environmental policy instruments need to be promoted to achieve a consistent approach to sustainability. One example is the need to ensure that measures for sustainable agriculture support and compensate as well as being supported and compensated by transport and energy policies. Further steps will need to be taken to develop an integrated decision-making system within Community institutions and committees.

A small number of major adaptations to the European Commision's proposed reform of the CAP could allow a move towards sustainable agriculture:

Cross-compliance should be made compulsory for all Member States in a form which ensures environmental progress. Ground rules and guidelines for cross compliance and for codes of good practice should be set at EU level, although setting nature and landscape conditions is best carried out on a national level.

The role of rural development should be enlarged and the approach made truly sustainable. To this end the budget for rural development should be substantially increased (at the possible expense of export subsidies) and greened in order to allow Member States to use this instrument more intensively. In addition to the agri-environment measures being compulsory (which is already the case), there should also be a clear earmarking of a substantial amount in the budget for such measures

The entire CAP reform should be subject to a comprehensive strategic environmental impact assessment (SEA). Such an SEA should cover the projected impact on the environment (including climate effect, biodiversity, landscape and animal welfare) of the full package of CAP measures as proposed. It should be mandatory that, based on the outcome of the SEA, further adjustments in the CAP are made in the near future.

Methods of sustainable agricultural development directly related to climatic effects, to be incorporated into European and global policy include methods for minimizing emissions of carbon dioxide, methane and nitrous oxides:

The goal for CO_2 reductions from the agricultural sector should be to make sure that the land is used as efficiently as possible, thereby maximizing the preservation of non-cultivated areas such as forests. This goal is particularly important in light of predictions which suggest that agricultural land could increase by 60% by 2025. Further, on cultivated lands, practices should aim to limit soil erosion through minimization of tillage practices. Finally, the use of more energy efficient farm implements should be promoted.

Realistic options for the reduction of methane emissions include the improvement of ruminant nutrition levels through feed additives. Waste management practices should strive to ensure aerobic conditions at all times to minimize potential CH_4 releases. Such practices include minimizing the lagooning of wastes (unless a methane collection system is present), prompt application of wastes as fertiliser on fields and the use of wastes as a fuel source. Research needs to continue on minimizing methane emissions from flooded rice paddies, possibly through the selection and development of cultivars and changes in the nutrient and water management practices.

Reducing nitrous oxide emissions from the agricultural sector requires improved nitrogen management, with the goal of leaving as little residual nitrogen as possible in the soil during non-cropped periods of the year. Practices for accomplishing this goal can be summarized as paying closer attention to the use and management of fertilizer techniques.

The Maastricht Treaty on European Union, which entered into force in November 1993 embodies the principle of sustainability and reinforced environmental policy by clearly stating the obligation of integrating environmental requirements in all EU policies.

Agriculture is one of the selected target sectors of the *Fifth Environmental Action Programme* adapted by the Commission in 1992. The programme lays down the fundamental objectives of maintaining the basic natural processes indispensable for a sustainable agricultural sector, through the conservation of water, soil and genetic resources. The Programme also sets out specific objectives namely, to reduce chemical inputs, to achieve a balance between nutrient inputs and the absorptive capacity of the soil and plants, to promote rural environmental management practices, to conserve biodiversity and natural habitats and to minimise natural risks. Climate change is included in the principal themes and targets of the Programme and is recognised as a particularly important problem due to the close link with various Community policies, including agriculture.

The EU is committed to support sustainable agriculture at the international level. To this aim the European Commission could contribute actively through its current participation in the works of the UN Commission on Sustainable Development which monitors the implementation of Agenda 21.

In view of the present uncertainties over the pace and magnitude of climate change, the most promising and most cost-effective policy options of agricultural adaptation are ones for which benefits accrue even if no climate change takes place. Small changes can be accommodated in the normal course of development. These would entail relatively little cost and would be incorporated into existing planning mechanisms without major institutional development. Such policy options include the following:

Liberalization of trade. Removing barriers to international trade in agricultural commodities, as under the GATT (now established within the WTO under the Uruguay Round), should help the world food system to adjust to climate changes more efficiently and rapidly.

Flexibility of commodity support programmes. Commodity support programs often discourage farmers from changing cropping systems, and this may hinder adaptation to climate change. Efforts to stabilize food supplies and maintain farm incomes should avoid disincentives for farmers to switch and rotate crops. Such a policy will induce greater efficiency in farming practices and promote flexibility in the face of future climate change.

Dissemination of conservation management practices. Conservation tillage, furrow diking, terracing, contouring, and planting windbreaks protect fields from water and wind erosion, and retain soil moisture by reducing evaporation and increasing infiltration. Use of biologically intensive management practices such as green manures, cover crops, intercropping, agroforestry, and crop rotation as well as the maintenance of ground cover and the introduction of shelter belts protect fields from soil erosion. Improving rainfed (dryland) farming can reduce dependence on irrigation, save water, and allow greater resiliency in adapting to climate change.

Agricultural drought management. Drought is an intrinsic feature of the climate prevalent in many agricultural regions . Mistakenly, it is commonly seen as a natural disaster rather as an inevitable occurrence (though of irregular frequency, duration and intensity). Drought management can be improved by providing information about climatic conditions and patterns, sound preparatory practices and options for the eventuality of drought, and appropriate insurance programmes. Farm disaster relief and other government subsidies, however, may distort markets and encourage the continuance and even expansion of farming marginal lands.

Promoting efficiency of irrigation and water use. Presently wasteful surface irrigation systems may be converted to more efficient sprinkle, drip and micro-spray techniques. Drainage water and wastewater may be reused for irrigation. Evaporation and seepage losses can be reduced by encouraging use of night time irrigation, lining of canals, closed conduits, delivery of water in measured quantities and charging for water in proportion to the volume used. Finally, and perhaps most important, water conservation should be promoted by means of public education and consciousness raising.

Protection of permanently flooded areas. Treating the symptoms, such as constructing flood banks to control the course of the river, comprise part of the flood control measures. However, the best solutions tackle the causes as well. Such measures consist of planting new trees in mountain areas; redistributing land so that people are not forced to live in flood areas; controlling climate change.

Improved short term climate prediction. Linking agricultural management to seasonal climate predictions (currently largely based on the El NiZo Southern Oscillation Phenomenon), where such predictions can be made with reliability, can allow management to adapt incrementally to climate change. Management/climate predictor links are an important and growing part of agricultural extension in both developed and developing countries.

Maintenance of seed banks. Collections of seeds are maintained in germplasm banks around the world. These genetic resources must be maintained in order to allow future screening for sources of resistance to changing diseases and insects, as well as tolerances to heat and water stress and better compatibility with new agricultural technologies.

New crop varieties and species. Selective breeding objectives should include heat tolerant and low water-use crops, as well as crops with high value per unit volume of water used. Salt-tolerant crops should be introduced in regions with brackish water supplies or vulnerable to soil salinization. More tolerant crops may enable farmers to diversify and to produce profitably even under adverse conditions.

Different crop varieties or species. If climate change affects the length of the growing season, then farmers should be encouraged to use the adaptation strategy of switching to longer growing, higher yielding cultivars. For most major crops, varieties exist with a wide range of maturation and climatic tolerances.

Investment in agricultural research and infrastructure. Adaptation cannot be taken for granted: improvements in agriculture have always depended on the investments made in agricultural research and infrastructure. Research can identify the specific ways that farmers now adapt to present variations in climate, whether by applying more fertilizer, more mechanization, or more labor. Information of this nature is needed to. Success in adapting to possible climate change will depend on a better definition of what changes will occur where, and on prudent investments, made in a timely fashion.

In Europe, climate adaptation policies will need to be combined with or added to existing EU agricultural policies and in particular the EU Common Agricultural Policy, in view of the European Commission's current proposed reform of the CAP as discussed above. The conservation of water, soil and genetic resources are included in the fundamental objectives of the *Fifth Environmental Action Programme* in relation to the agricultural sector. Agricultural research leading to an assessment of potentialities for coping with the threat of a more severe climate in the future should be incorporated into the agricultural and other relevant research programmes implementing the European Community *Fifth Framework Research Programme* (1998-2002). An assessment of the costs and benefits of prevention policies versus alternative adaptation policies regarding the effect of prospective climate change on agricultural production should also be a subject for further research.

The aim of adaptation is to avoid crises. However, if present strategies to handle climatic hazards are insufficient, further disaster preparedness is warranted and may be justified in part for as a means to reduce the risk of large-scale impacts from climate change. A climate change catastrophe scenario would be the collapse of major regional ecosystems, such as fishing grounds, coastal settlements, and semi-arid agriculture. It is likely that planned resilience and purposeful adaptation would be less costly than coping with such large scale effects. In any case, coping with crises often fails to mitigate future disasters and has a high opportunity cost. (T.E. Downing 1998).

1. INTRODUCTION

> *No country can opt out of global warming or fence in its own private climate. We need common action to save our common environment. (...) If greenhouse emissions continue to rise unabated, by the year 2100 global temperatures will have gone up by 1 to 3.5 ° centigrade and sea levels risen by perhaps as much as a metre.*
>
> Speech by the Prime Minister, The Rt. Hon Tony Blair MP (UK), to the United Nations Special Session on the Environment (UNGASS), 23/07/98
> (Blair, 1998)

Whereas the negotiations on the Climate Convention in the early nineties were based on the precautionary principle, the Second Assessment Report from the Inter-governmental Panel on Climate Change (IPCC), published early 1996, goes a step further by acknowledging that "*the balance of scientific evidence suggests that there is a discernible anthropogenic influence on the global climate"* (Communication, 1998).

> *When we first started talking about a hole in the ozone layer or the greenhouse effect, science was clearly unable to make any categorical statements on these threats due to a lack of knowledge and understanding of the extraordinary complex mechanisms involved in the physics and chemistry of the atmosphere. Since then, there has been a wide-ranging consensus in Europe in favour of a major research effort in order to get to grips with these problems.*
>
> Christian Patermann, Director of DGXII's Environment and Climate Programme
> (Patermann, 1998)

Although the climate dialogue is now marked by growing alarm over the risks the world faces and the theory of the enhanced greenhouse effect and the prospective of a global climate change have gained wide acceptance among scientists and policy-makers, there is still a debate driven by the so-called climate sceptics who argue that computer - generated models are too flimsy to be predictive, that the temperature record shows a slower rate of warming than the models suggest, or the "negative feedbacks" will protect us from climate change (see Balling, 1995; Kerr, 1989; Lidzen, 1993; Lee, 1996).

However, the fact that under the Kyoto Protocol, which was adopted by consensus in December 1997, industrialised countries have a legally binding commitment to reduce their collective greenhouse emissions by at least 5% compared to 1990 levels by the period 2008-2012, shows that Climate Change is a prospective we can not ignore.

1.1 Natural Climate Variations

The sun emits solar radiation mainly in the form of visible and ultraviolet (UV) radiation. As this radiation travels toward the earth, 25% is absorbed by the atmosphere and 25% is reflected by the clouds back into space. The remaining radiation travels unimpeded to the earth and heats its surface. Many atmospheric trace gases trap the infra-red radiation emitted by the earth's surface. The atmosphere acts like the glass in a greenhouse, allowing short-wave UV radiation to travel through relatively unimpeded, but trapping some of the long-wave infra-red (IR) radiation which is trying to escape. This is the *earth's natural greenhouse effect* and keeps the earth at an average 15 °C.

The overall state of the global climate is determined by the balance of solar and terrestrial radiation budgets. The main processes which determine the overall state of the climate system are heating by incoming short-wave radiation (ultra-violet and light energy) from the sun and cooling by long -wave (infra-red) radiation from the earth into space.

How this energy balance is regulated depends upon the fluxes of energy, moisture, mass and momentum within the global climate system, made up of its 5 components, the atmosphere, the oceans, the biosphere, the geosphere and the cryosphere.

A process which alters the energy balance of the climate system is known as a radiative forcing mechanism, separated into external and internal. External forcing mechanisms operate from outside the earth's climate system, and include orbital variations (the Milankovitch Cycles) and changes in the solar flux. An internal forcing mechanism operates from within the climate system (e.g. volcanic activity and changes in the composition of the atmosphere). Orbital forcing operates over thousands of years whereas volcanic eruptions affect the energy budget for at most 2 to 3 years and solar variations may force climate change over a number of different time scales.

The climatic system is continually adjusting to forcing perturbations and the climate alters. A change in one part of the climate system, initiated either by internal or external forcing mechanisms, has much wider consequences as the initial effect cascades through the coupled components of the climate system. This process is known as feedback (GCCIP, 1998). The concept of feedback is related to the climate sensitivity or climate stability. In general terms, an initial change in temperature dT(forcing), is modified by feedback such that:

$$dT(\text{final}) = dT(\text{forcing}) + dT(\text{feedback})$$

1.2 Greenhouse Gases

Greenhouse gases (GHGs) have been present in trace quantities in the atmosphere for the great majority of earth's history. They are gases which cause infra-red radiation to be retained in the atmosphere, so warming the lower part of the atmosphere and the earth (IPCC, 1990). A variety of gases contribute to the earth's greenhouse effect. The most important are water vapour and carbon dioxide (CO2). Others which also occur naturally are methane (CH4), nitrous oxide (N2O) and ozone (O3). A wide range of human activities result in the release of greenhouse gases, particularly carbon dioxide, methane, nitrous oxide and chlorofluorcarbons (CFCs) which are manufactured gases and have an extremely potent greenhouse effect (Table 1.1).

Anthropogenic emissions can be categorised as arising from energy production and use, non-energy industrial activities (primarily the production of CFCs), agricultural activities and changes in the land-use patterns (including deforestation and biomass burning). The relative direct sources of GHGs are shown in Table 1.1. The relative estimated contributions of these activities to radiative forcing during the 1980s are :

- Energy 46%
- CFCs 24%
- Forestry 18%
- Agriculture 9%
- Other activities 3%.

The concept of relative global warming potentials (GWPs) has been developed as an index of the relative radiative effect of equal emissions of each GHG to take into account the differing time that they remain in the atmosphere and their different absorption properties (Table 1.1). The GWP defines the time-integrated warming effect due to an instantaneous release of unit mass (1kg) of a given gas in today's atmosphere, relative to that of carbon dioxide (EEA, 1995).

The natural presence of greenhouse gases in the atmosphere is essential for life. However, by increasing their concentration, additional infra-red radiation is absorbed in the lower atmosphere and the earth's balance is upset.

This energy is re-emitted in all directions, a large portion being sent back to the earth's surface or elsewhere in the troposphere. This yields a radiative imbalance which can be restored only through a warming of the troposphere (EEA, 1995).

It should be noted that carbon dioxide, and thus the cycle of life, plays a significant role in the process of global warming. Carbon dioxide and temperature have been very closely correlated over the past 160,000 years (Figure 1.1) and to a lesser extent, over the past 100 years (Figure 1.2). The long-term record, based on evidence from Antarctica, shows how the local temperature and atmospheric CO_2 rose nearly in step as an ice age ended about 130,000 years ago, fell almost simultaneously at the onset of a new glacial period, and rose again as the ice retreated about 10,000 years ago. The recent temperature record shows a slight global warming as traced by workers at the Climate Research Unit of the University of East Anglia (Leggett, 1990).

1.3 Aerosols

Aerosols are conventionally defined as those particles, solid or liquid, which are small enough to remain suspended in the air, of diameter 0.001 to 10µm. Although making up only 1 part in a billion of the mass of the atmosphere, aerosols have the potential to significantly influence the amount of short-wave solar radiation arriving at the earth's surface. Aerosols are important due to their role as participants in chemical reactions in the atmosphere and as absorbers and scatterers of solar radiation where they are considered as negative radiative forcing agents. This is clearly demonstrated in the aftermath of a volcanic eruption. Natural origins, which are probably 4 to 5 times larger than anthropogenic ones on a global scale, include salt particles from sea spray and clay particles as a result of weathering of rocks.

Aerosols that originate as a result of man's activities are often considered pollutants. The recent increase in anthropogenic aerosol emissions partially offsets some of the increase in greenhouse radiative forcing due to the elevated concentrations of GHGs (GCCIP, 1998). In 1994, the Hadley Centre for Climate Prediction and Research at the Meteorological Office in Bracknell, England, incorporated the aerosols in its Global Circulation Model, and succeeded in mimicking global temperature records over the past century far more closely than earlier models did. As indicated by the Hadley model, the earth is in fact warming more rapidly in the southern hemisphere than in the North, where part of the warming effect of greenhouse gases is negated by this aerosol haze (HCCPR, 1995) .

1.4 Recent warming

Scientists at the Goddard Institute for Space Studies in the USA have assembled temperature records from monitoring stations around the world that go back to 1866 (Figure 1.2). According to their data, the global average temperature at the surface of the earth in the mid-1990s (15,27 degrees Celsius) was 0.6 degrees Celsius warmer than the average temperature recorded in the 1890s. This makes the 1990s the warmest decade on record so far, despite a sharp cooling after the Mount Pinatubo volcano erupted in 1991 (Flavin and Tunali, 1996).

Combined land and ocean temperatures have increased rather differently in the two hemispheres. A rapid increase in the Northern Hemisphere temperature during the 1920s and 1930s contrasts with a more gradual increase in the Southern Hemisphere. Both hemispheres had relatively stable temperatures from the 1940s to the 1970s, although there is some evidence of cooling in the Northern Hemisphere during the 1960s. Since the 1960s in the Southern Hemisphere and after 1975 in the Northern Hemisphere, temperatures have risen sharply (GCCIP, 1998). Although temperatures fluctuate naturally from year to year and decade to decade, it is striking that all ten of the warmest years since record-keeping began have occurred since 1980 (Flavin and Tunali, 1996).

Data on the timing of the seasons may provide another indicator of climate change. According to David J. Thomson who published an article in *Science* on the changes in seasonal cycles in Europe incorporating data from as far back as 13th-century church records, the timing of the seasons began to shift in the 1940s after centuries of relative stability, showing a close correlation with the rise in concentrations of greenhouse gases (Thomson, 1995).

Whilst globally-averaged records offer a means of assessing climate change, it is important to recognise that they represent an over-simplification. Significant latitudinal and regional differences in the extent and timing of warming exists. (GCCIP, 1998).

2. PROSPECTIVE ENVIRONMENTAL EFFECTS OF GLOBAL WARMING

> *Climate change is a threat to mankind. But no one is certain about its future effects or their severity. Responding to the threat is expected to be expensive, complicated and difficult.*
>
> (UNEP, 1998)

In general terms, climate models predict that the global average temperature will rise by about 2 ^{o} C by the year 2100 if current emission trends continue (UNEP/IUC/f.s.2, 1998). This projection uses 1990 as a baseline. It also takes into account climate feedback and the effects of sulphate aerosols as they are presently understood. Because there are still many uncertainties, current estimates of how much it will warm during the 21st century range from 1 to 3.5 ^{o} C.

However, it is still too early to predict the size and timing of climate change in specific regions. Current climate models are only able to predict patterns of change for the continental scale. Predicting how climate change will affect the weather in a particular region is much more difficult. Thus the practical consequences of global warming for individual countries or regions remain very uncertain (UNEP/IUC/f.s.2, 1998).

2.1 Possible changes in the frequency and/or intensity of extreme events

The frequency and intensity of extreme events such as storms and hurricanes may change. However, models still cannot predict how. The models used to simulate these extreme weather events cannot themselves simulate these events, so the evidence is indirect. There is some concern that patterns of extreme weather may change because the models predict changes in ocean surface temperatures and other factors that are known to affect storm and hurricane development. However, it will be many years before scientists can predict whether individual regions will become more or less stormy.

Among the extreme events that may become more frequent or intense in some regions are coastal storm surges, floods and landslides induced by local downpours, windstorms, rapid snow-melt, tropical cyclones and hurricanes and drought-induced forest and bush fires (UNEP/IUC/f.s.15, 1998).

A scientific assessment for a German insurance company, Munich Re, notes : “A warmer atmosphere and warmer seas result in greater exchange of energy processes so crucial to the development of tropical cyclones, tornadoes, thunderstorms and hailstorms”. Meteorologist Kerry Emanual of the Massachusetts Institute of Technology estimates that a 3-4 degree Celsius rise in sea temperatures projected by atmospheric models could increase the destructive potential of hurricanes by 50% and cause sustained storm winds as high as 350 km per hour (Flavin and Tunali, 1996).

2.1.1 Floods

Records on recent flooding and on paleoflooding indicate the high sensitivity of flood occurrence to changing climate for river basins in the USA and Europe. Analyses also indicate that there is no simple proportionality between the scale and frequency of floods and climate variations. However, in general, increases in precipitation lead to proportionally larger increases in runoff.

Climatic change can have considerable repercussions on the flood regime. The predicted variation in storm magnitude and frequency would give rise to a spectacular increase in runoff in short periods of time, which would aggravate the already catastrophic effects of flooding (ETCIW, 1996). Moreover, any rise in sea level increases the risk of flooding. This is particularly the case if global warming is associated with fiercer storms and hurricanes (Foley, 1991).

2.1.2 Droughts

Drought is a period of abnormally dry weather over a prolonged time period sufficient to cause a serious hydrological imbalance in the affected area. This can cause such problems as crop damage and water-supply shortage. The severity of the drought depends upon the degree of moisture deficiency, the duration of the drought and the size of the affected area (GCCIP, 1998).

A variation in the risk and intensity of droughts is the most serious negative impact of climatic change on water resources. A reduction in water availability could lead to desertification in zones where the balance is particularly fragile (ETCIW, 1996). In the temperate regions, the impacts of climate variability, particularly drought, on yields and grains (e.g., in North America and the former Soviet Union) have been of particular concern because of its effects on world food security. In tropical and subtropical regions, drought impacts on agriculture and the resulting food shortages have been widely studied, especially when associated with the failure of the monsoon in Asia or the rains in Sudano-Sahelian Africa (Rosenzweig and Hillel, 1998). In these regions, droughts are often associated with famine and widespread social unrest (Pierce, 1990).

Recent climatic models have apparently shown patterns of drought increasing in frequency from 5 per cent under the present climate to 50 per cent of the time by the year 2050 (Legget, 1990).

2.1.3 Relations between climate change and natural periodic phenomena such as El Niňo.

Warm/El Niňo and cold/La Niňa episodes are extremes of what is often referred to as the ENSO cycle (CPC/NCEP, 1998). El Niňo is a climatic phenomenon occurring every 2 to 7 years during Christmas (El Niňo means Christ child) in the surface oceans of the SE Pacific. The phenomenon involves seasonal changes in the direction of Pacific winds and abnormally warm surface ocean temperatures. The changes normally only affect the Pacific regions, but major events can disrupt weather patterns over much of the globe (GCCIP, 1998) .

The North Atlantic Oscillation (NAO), on the other hand, affects the circulation of seas at the North Atlantic's margins. In terms of measurement, the NAO is an index created by comparing the pressures in the Azores and in Iceland. The relationship between these events and global weather patterns are poorly understood and are currently the subject of much research.

The atmospheric circulation is the main control behind regional changes in wind, temperature, precipitation, moisture and other climatic variables. Variations in many of these are quite strongly related through large-scale features of the atmospheric circulation.

Changes in a number of circulation features, including El Niňo Southern Oscillation events, mid-latitude Northern Hemisphere westerlies and the location and intensity of the Aleutian low pressure system in the North Pacific, may all be related to increased global warming in the twentieth century (GCCIP, 1998).

Keeling et *al* (Keeling et *al*, 1983) and Siegenthaler (Siegenthaler , 1990) suggest that the above mentioned natural periodic phenomena of recent years are due to changes in the metabolism of forests related to drought, associated with the complex series of changes in oceanic circulation. While there is an understandable tendency to look for subtleties in such a complicated system, the potential of a simple change in temperature for changing rates of respiration regionally or globally is great enough to swamp subtleties (Leggett, 1990).

Nevertheless, the possibility that a recent upturn in the frequency of El Niňo Southern Oscillation events, NAO and other natural fluctuations, may be due to anthropogenic causes associated with global warming, will have to be re-evaluated (Global Environmental Change Report, 24 October 1997).

2.1.4 Increase in storm-surge hazards

Flooding due to storm surges already affects some 46 million people in an average year, most of them in developing countries. Studies suggest that this figure could increase to 92 million with a 50 cm sea-level rise, and to 118 million with a one-metre rise. If expected population growth is incorporated into the projections, these estimates increase substantially (UNEP/IUC/f.s.15, 1998).

World-wide, erosion of coastlines, beaches and barrier islands has accelerated over the past decades as a result of rising sea level. Increased erosion would decrease natural storm barriers. Coastal floods associated with storm surges surpass even earthquakes in loss of life and property damage worldwide (Jacobson, 1990). A one-metre sea level rise could turn a moderate storm to a catastrophic one. Oceanographer T.S.Murty states that as cultivation and habitation of newly formed low-lying delta land continues, even greater storm surge disasters must be anticipated (Murty, 1985).

2.2 Sea level rise

The global average sea level has risen by 10 to 25 cm over the past 100 years. It is likely that much of this rise is related to an increase of 0.3 -0.6 ^{o} C in the lower atmosphere's global average temperature since 1860 (UNEP/IUC/f.s.11, 1998).

The IPCC (1996) has predicted that continuation of current trace gas and aerosol emmission rates will cause mean sea level to rise at the rate of about 5 cm per decade. Such a rate of sea level rise could result in a total rise of 25 cm by the year 2050 and about 50 cm by 2100. The uncertainty range is large (15 to 95 cm) and changing ocean currents could cause local and regional sea levels to rise much more or much less than the global average (UNEP/IUC/f.s.5, 1998). A rise of sea level by 30-50 cm would affect the habitability of low-lying coastal regions significantly and one metre rise would impact 360,000 Km of coastline, render some island countries uninhabitable, displace tens of millions of people, threaten low-lying urban areas, flood productive land and contaminate fresh water supplies (IPCC, 1990).

The main source of this rise is the thermal expansion of the upper layers of the ocean as they warm, with some contribution from melting glaciers. Slightly faster melting of the Greenland and Antarctica ice sheets is likely to be balanced by increased snowfall in both regions. As the warming penetrates deeper into the oceans and ice continues to melt, sea level will continue rising well after surface temperatures have levelled off (UNEP/IUC/f.s.5, 1998).

The projected rise is two to five times faster than the rise experienced over the past 100 years. The rate, magnitude and direction of sea-level change will vary locally and regionally in response to coastline figures, changes in ocean currents, differences in tidal patterns and sea-water density, and vertical movements of the land itself. Sea levels are expected to continue rising for hundreds of years after atmospheric temperatures stabilise.

A number of projects conducted under the Environment and Climate Programme of the European Commission have reached the same conclusion: sea levels are rising along Europe's coastlines at an average rate between 1 and 1.5 millimetres per year. Although this may be partly due to certain vertical tectonic movements affecting the sea beds, researchers working on a European project have shown that the melting of glaciers is also contributing to this rise in sea levels (Europa/DGXII, 1998).

Some coastal areas in Europe already are beneath mean sea level, and many others are vulnerable to storm surges. Areas most at risk include the Dutch, German, Ukrainian and Russian coastlines, some Mediterranean deltas, and Baltic coastal zones.

2.3 Hydrology and water resources

The water cycle plays an extremely important and reciprocal role in the climatic system, both conditioning the climate and being affected by it (ETCIW, 1996). Because they still lack confidence in regional scenarios, scientists are uncertain about which areas of the world risk becoming wetter and which drier. But with global water resources already under severe strain from rapid population growth and expanding economic activity, the danger is clear (UNEP, 1998).

Water resources vary widely across Europe. One third of European countries have relatively low availability of water, and southern countries are particularly affected (EEA, 1997). Water supply may be affected by possible increases in floods in northern and north-west Europe and by droughts in southern portions of the continent (EPA, 1998).

2.3.1 Precipitation

Changes in precipitation can bring about changes not only to the runoff magnitude and temporality, but also to the frequency and intensity of storms and droughts. Temperature changes undoubtedly cause alterations to the evapotranspiration, soil moisture and seepage to the deepest layers. Such changes in the surface water-content modify the vegetation cover, which brings about a chain reaction, affecting cloud formation, the earth's albedo and precipitation (ETCIW, 1996).

The parameters that affect evaporative demand are temperature, net radiation, atmospheric humidity and windiness. In the global hydrological cycle, water evaporated must be precipitated; hence, more evaporation implies more rainfall overall. However, increases in potential evapotranspiration and in rainfall may not be commensurate or concurrent in all locations (Rosenzweig and Hillel, 1998).

Predictions of surface run-off are vulnerable to the same uncertainities that afflict other aspects of the effects of global warming. Within narrow limits, perhaps within a warming of 1-2 ^{o} C for the earth as a whole, general patterns seem clear. Beyond that range uncertainity dominates (Legget, 1990).

General circulation models (GCMs)[1] indicate an intensification of the global hydrological cycle as a result of global warming. At a doubling of the atmospheric CO_2 concentration (expected at about 2070) the estimated increase in mean annual global precipitation varies from 3 to 15% (Greenpeace, 1998). Meanwhile, global evapotranspiration could increase 5-10% (OTA 1993).The general consensus is that greater amounts of rainfall (10 to 20%) should be expected in much of the mid-latitudes during winter (i.e. northwest Europe), as well as increases at high latitudes throughout the year, and in areas affected by monsoon rainfall (India, Northern Australia). Whenever investigated, there is qualitative agreement between most models on a shift towards more heavy rainfall events and higher rainfall intensities. Similarly, there is consensus that in arid and semi-arid areas (such as Southern Europe and North Africa) the amount of rainfall is expected to decrease or remain more or less constant (Greenpeace, 1998).

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[1] At the moment, the four major coupled atmosphere-ocean GCMs are the high-resolution climate model of the United Kingdom Meteorological Office (UKMO, Hadley Centre, Bracknell), the climate model of the National Center of Atmospheric Research (NCAR, Boulder, USA, without flux correction), the Geophysical Fluid Dynamics model (GFDL, Princeton, USA), and the MPI model (Max-Planck-Institut für Meteorologie, Hamburg, Germany) (Greenpeace, 1998).

2.3.1.1 Mid and high latitude regions

In the mid-latitude temperate zone, weather is controlled by alternating or clashing tropical and polar air masses. Precipitation here occurs primarily along fronts of cyclonic storms, although convective storms occur in the summer season. The temperate region also has many different climate subregions with warmer and cooler temperatures, characterised by seasonal patterns of rainfall.

Climate models suggest that potential evapotranspiration tends to rise most where the temperature is already high (i.e. in low to mid-latitudes), while precipitation tends to increase most where the air is cooler and more readily saturated by the additional moisture (i.e. in higher latitudes and near seacoasts). Thus, drier conditions may occur in many of the world's most important agricultural regions, a consequence that could have great practical importance (Rosenzweig and Hillel, 1998).

Total precipitation is predicted to increase, but at the local level trends are much less certain. Wintertime precipitation in the far north is likely to rise, but what happens in mid-latitudes and in the tropics depends very much on the details of the particular climate model and the emission scenario (UNEP/IUC/f.s.5, 1998).

More rain and snow will mean wetter soil conditions in high-latitude winters, but higher temperatures may mean drier soils in summer. Local changes in soil moisture are clearly important for agriculture, but models still find it difficult to simulate them (UNEP/IUC/f.s.5, 1998).

Most of Europe experienced temperature increases this century larger than the global average, and enhanced precipitation in the northern half and decreases in the southern half of the region. Projections of future climate, not taking into account the effects of aerosols, indicate that precipitation in high latitudes of Europe may increase, with mixed results for other parts of Europe. The current uncertainties about future precipitation are mainly exacerbated by the effects of aerosols (EPA, 1998).

2.3.1.2 Tropics and sub-tropics

Approximately 75% of the world's people live in the tropics, and two - thirds of them rely on agriculture for their livelihood. Societies in the tropics tend to be more dependent on agriculture than those in the temperate regions, and therefore may be more vulnerable to climatic change.

Climatologically, the tropics are characterised by perennially high temperatures. Tropical precipitation is primarily convective. In the more humid subregions, annual rainfall is often above 2,000 mm and occurs year round. In the drier tropics, however, rainfall tends to be seasonal and its total may not exceed 500 mm. The greater part of the tropical region lies between these precipitation levels with distinct wet and dry seasons (Rosenzweig and Hillel, 1998).

The effects on the tropics are harder to predict. Different climate models produce different results for the future intensity and distribution of tropical rainfall (UNEP/IUC/f.s.13, 1998). Climate models have predicted larger temperature rises in temperate regions than in tropical regions. These projections have led to the assumption that climate change impacts in the tropics should be less severe than in the temperate zone (Rosenzweig and Liverman, 1992).

The projections of changes in the hydrological cycle are uncertain, showing a mixed picture of regional precipitation increases or decreases in parts of the tropical zone. There is some indication, however, that increased drought conditions will be manifested first in tropical regions and then spread to temperate regions in later decades (Rind et al., 1990)..

2.3.2 Underground water reservoirs

Changing precipitation patterns will affect how much water can be captured. Several models suggest that downpours will become more intense. This would increase floods and runoff while reducing the ability of soil to infiltrate the water. Changes in seasonal patterns may affect the regional distribution of both ground and surface water supplies.

Reservoirs and wells would be affected. Changes at the surface would influence the recharging of groundwater supplies and, in the long term, aquifers. Water quality may also respond to changes in the amount and timing of precipitation (UNEP/IUC/f.s.13, 1998).

Groundwater is the main source of freshwater in many coastal areas, especially in arid and semiarid regions. Rising seas could invade coastal freshwater supplies. Coastal aquifers may be damaged by saline intrusion as salty groundwater rises. The movement of the salt-front up estuaries would affect freshwater pumping plants upriver. (UNEP/IUC/f.s.13, 1998).

With climate change and sea-level rise, the saltwater - groundwater interface will tend to migrate landward, and the salinity front will begin to penetrate further upstream. Drainage will be impeded due to rising water table levels. The combination of sea-level rise and an intensified hydrological regime and flooding could damage agricultural productivity and local fisheries in many coastal zones (Rosenzweig and Hillel, 1998).

It should be noted that European cities have 140 million people living in or near areas of groundwater over-exploitation (EEA, 1997). In other words, these regions tend to withdraw more groundwater than can be recharged, and any increased drought caused by climate change could accelerate the mining of groundwater (Legget, 1990).

2.4 Effects on forests and major ecosystems

Forests, climate change and biodiversity: these three issues overlap with their convergence point being the forest's dual role as habitat and carbon sink. Forests cover more than one third of the land surface of the Earth and account for 80 to 90% of plant and 30 to 40% of the soil carbon. Because tropical and temperate forests are the terrestrial biomes with the most biomass, they have the highest potential for carbon storage as wood fibre and leaf canopy. At the same time, the many levels of the forest canopy, with their varying light intensities and moisture levels, allow a multitude of habitats to coexist in a small area, creating the most favourable conditions for biodiversity. Preserving forests thus contributes to both climate stability and biodiversity goals.

The world's forest estate has declined significantly in both area and quality in recent decades. The major causes of this decline are deforestation and air pollution, with climate change, storms and fires aggravating the situation. For assessing the impact of environmental conditions on the growth and performance of forests it is important to study areas where significant change is expected and where the forest ecosystems are of socio-economic importance. The following systems have initial priority:

- Boreal forests, which contain much of the world's available softwood and have high stores of organic matter. It is predicted that boreal areas will experience considerable warming as a result of climate change. In those regions physiological responses to enhanced CO_2 are likely to be limited by current low temperatures and infertile soils

- Temperate coniferous and mixed coniferous-deciduous forests, which form the basis for most of the world present timber and pulp industry.

- Humid tropical and sub-tropical forests, which have the greatest bio-diversity. These forests are under intense land-use pressures and may be highly responsive to CO_2 except where nutrient availability is low.

- Semi-arid forests, which are expected to be particularly sensitive to altered moisture availability, are globally extensive, and are under considerable land-use pressure. Such areas include woodlands in Asia and Africa, eucalypt and soft-wood plantations in Mediterranean climate zones, managed native eucalypt stands in Australia, and semi-deciduous forests in South America.

2.4.1 Increased wind damage and increased risks of forest fires

Storms is one of the factors causing forest damage. O'Brien et al (1992) considered the impact on tropical forests of changes in hurricane frequency or intensity. Over the last 20 years a new phenomenon is occurring in the moist tropical forests as a result of road building and logging: forest fires, previously rare in wet forest types, have become common. The fires that raged Indonesia and Brazil in 1997 and 1998 are part of this new ecological pattern. The fires in Indonesia spread to at least two million hectares of forest. A drought induced by El Niño aggravated the situation.

In Europe, fire is one of the major problems for forest conservation, especially in the southern countries of the EU. During 1980-1990 the number of fires in the EU increased, although the area burnt did not increase by the same proportion. An average of 500,000 ha. of wooded land were burnt per year.

Forests are highly sensitive to climatic change, and global change is likely to have its greates impact on boreal forests. Boreal forests account for about a third of carbon sequestered in terrestrial ecosystems, so changes in their functioning or distribution could create important feedbacks to the climate system. Warming could cause boreal forests to change from being a component of the missing sink of carbon dioxide, if they are accumulating carbon, to being a net source if warming greatly increases fire frequency or decomposition. The rate of change in boreal forests is governed by fire frequency and severity, with important immediate and long term effects on carbon and energy flows.

Fire return time in the boreal forest ranges from 50-500 yr. This fire regime is variable because of its sensitivity to vegetation, topography, climate (especially short-term extreme fire-weather events), and human activities (both an ignition source and an agent of fire control). Fire models that include CO_2-induced climatic warming predict a 46% increase in fire severity rating and a 40% increase in area burnt. Recent warming trends are correlated with a more than doubled annual area burnt in the Canadian boreal forest. However, the correlation between fire weather severity and area burnt cannot be linearly extrapolated into the future, both because many factors (e.g., level of protection) confound the current fire-climate correlation, and because it is quite likely that there are important thresholds and non-linearities in the causes and consequences of boreal fire. For example, even if high-latitude warming occured primarily in winter/spring, it could lengthen the fire season by 30%, acting as a potent multiplier to changes in average montly fire probability and expand the geographic area of extreme fire danger.

2.4.2 Shifts of vegetation boundaries

On the basis of current models for temperate latitudes, we can expect a shift polewards of vegetation zones amounting to several hundred kilometres for each degree rise in global temperature. 'Migration' of the forest at the end of the last glacial period has been calculated as having taken place at a rate of 20-100 km per century. The tree line could have possibly moved a little more quickly had the temperature risen more quickly, but a global temperature increase of 3^0 C in the next fifty years would correspond to a rate of warming 50 times faster than that at the end of the last ice age. It seems highly probable that many tree species will be unable to respond quickly enough to the current rate of climatic change to be saved from extinction, even though a suitable environment may continue to exist in which they would actually be able to grow. According to estimates boreal forests would decline by 40% and temperate forests by 1.3%, whereas tropical forests would rise by 12%. The net change would amount to a decline of 3.7% globally in biomass and 5.8% in area.

2.4.3 Influence of climate change on sensitive stages in trees' life cycle

Impact studies on young forest trees have shown that growth and development are speeded up: the trees get bigger quicker. Young trees grown in double the present atmospheric CO_2 concentration achieve the size and developmental stage after four years that is reached by trees in the current ambient CO_2 concentration after about six years, provided that nutrients are available.

However, although the enhancement of plant growth and yield in CO_2 enriched environments has been well documented in short term experiments, it still remains unclear whether enhanced atmospheric CO_2 concentrations will continue to stimulate growth and productivity of woody species in the long term (i.e. several years). Increased concentrations of atmospheric CO_2 also result in an increased demand by trees for other resources, such as nutrients. When nutrient supply rates do not meet growth rates, plant nutrient status declines and nutrients become limiting. Even without nutrient and water stress, the increment of dry mass of many species may be limited in densely growing stands or natural systems in a future higher CO_2 world. This may be attributed to competition, CO_2 losses in respiration and carbon release to soils by root exudation. (R. Ceulemans, 1998).

Forests typically take centuries to adapt to new conditions and so would be especially hard-hit. Sensitive stages in the life cycle of most tree species - including pollination, flower production, and seed germination- would be upset by climate change.

2.4.4 Potential climatic stress factors

Large daily amplitudes of temperature might cause stress in low lying areas or at south exposed mountain slopes. Periods of extreme high and low temperature as well as sudden drops in temperature are thought to cause stress. Temperature drops become more severe with increasing height above sea level. Low temperatures occur also at low levels, but only under radiation conditions, whereas low temperatures at higher altitudes are usually combined with high windspeeds, which make the situation even harsher.

Apart from temperature the water balance constitutes an important factor for tree growth. Periods of drought belong to the dominant natural factors causing stress for the vegetation. Reduced precipitation, enhanced temperature and evaporation over a certain period of time might finally end up as dry periods for the plants. During spring water reserves might still be plenty because of the winter precipitation while during summer with fully developed photosynthesis and higher temperatures a lack of precipitation can significantly reduce tree growth. During winter a series of clear days with intense radiation can cause the tree to photosynthesise and consume water reserves by transpiration. In case of a frozen soil, water cannot be replenished and a drought like situation is caused. Trees at the tree line on southerly exposed slopes and reduced snow cover are prone to this phenomenon.

Recently, temperature records over 100 years from Switzerland and Austria were analysed and conclusions concerning long term trends and the probability of extreme temperatures can be drawn. Not only is there a long term trend in temperature recorded in both countries corresponding with the global trend but also an amplification of global temperature variations in the Alps. Furthermore, the probability of extreme low temperatures has been decreasing more than the probability of high temperatures has been increasing in Switzerland. As a result of these chnages, there are indications that the alpine-nival flora has been moving higher in western Austria and eastern Switzerland during the last 70 to 90 years. (H. Scheifinger, 1998)

2.4.5 Climate change impact on forest resources

Changes in temperature and precipitation are likely. The most drastic changes have been predicted to take place in the northern laitudes, which are mostly covered by boreal forests. The predicted global climate change is among the major factors affecting the future development of forests in the boreal zone. In Finland, warming has been predicted to be more pronounced during the winter season than during the other seasons. Moreover, the growing season has been predicted to increase in length.

The tree species composition is likely to be altered under the climate change. A study on climate change impact on forest resources in Finland (A. Talkkari, 1998) shows that in southern Finland the proportion of Pendula birch in the growing stock may increase due to its competitive capacity under increasing temperature, while the proportions of Scots pine and Norway spruce may even decrease. In northern Finland, the growth potential of Scots pine may increase the volume of the growing stock even without a climate change. However, due to climate change, the volume of Norway spruce and Pendula birch may increase substantially in northern Finland. The simulations showed that the annual growth could increase, on average, by 21%, and the annual felling yield, on average, by 22%.

3. EFFECTS ON AGRICULTURE

Agriculture is sensitive to short term changes in weather and to seasonal, annual and longer term variations in climate. Over the long term, agriculture is able to tolerate moderate variations about the climatic mean. Changes beyond these bands of tolerance may require shifts in cultivars and crops, new technologies and infrastructure, or, ultimately conversion to different land uses.

The contribution of agriculture in the European Union is 2.5% of gross domestic product, ranging from 1.2 to 14.2% for individual countries. If only 10% of agricultural income depends on the weather, then several billion ECUs are at risk due to climatic variations each year. Understanding the effects of present weather and preparing for the impacts of future climate change on agriculture is thus essential.

Since the late 1950s, global agricultural output has increased at rates and to levels that are unprecedented in human history. Much of the productivity increase is attributed to the breeding of high yielding crop varieties, intensive use of inorganic fertilizers and pesticides, expansion of irrigation, and capital-intensive farm management.

In the late 1970s, the euphoria surrounding the 'Green Revolution' was questioned in the wake of the energy crisis and growing awareness of long term environmental consequences. Concern over soil erosion, groundwater contamination, soil compaction and decline of natural soil fertility, and destruction of traditional social systems, led to a reappraisal of what were then considered to be the most advanced agricultural production techniques. Since then, agricultural research has expanded its scope to include sustainable and resource efficient cropping systems and farm management practices.

Since the beginning of the 1980s yet another threat to agriculture has attracted much attention. Many climatologists predict significant global warming in the coming decades due to increasing atmospheric carbon dioxide and other trace gases. As a consequence, major changes in hydrological regimes have also been forecast to occur. Changes in temperature, precipitation, and solar radiation will have an effect on the productivity of crop and livestock agriculture. Climate change will also have economic effects on agriculture, including changes in farm profitability, prices, supply, demand, trade, and regional comparative advantages. The magnitude and geographical distribution of such climate-induced changes may affect our ability to expand food production as required to feed a population of more than 10000 million people projected for the middle of the next century. Climate change could thus have far-reaching effects on patterns of trade among nations, development, and food security.

The agronomic impacts of global climate change will depend upon how temperature, precipitation, and solar radiation change over time. Crop yields are critically influenced by these climate factors, as well as by the type of soil and the type of plant that is being grown. Studies that have examined how global climate change may affect agricultural productivity of various regions have generally combined predictions of climate models with crop simulation models to predict yield effects due to a changing climate.

3.1 Shift in Climate and Agricultural Zones

General circulation models based on the equivalent of doubling CO_2 concentration have predicted a global increase in mean global temperature ranging from 1 to 3.5 ^{0}C. Furthermore, all current models show that the increase will be unequally distributed globally. For example, it is predicted that temperature rise in higher latitudes will be much more than in equatorial regions. Models also predict a change in precipitation with some regions receiving more rain than the present and others receiving much less rain.

Various regions of the world will be impacted differently under climate change, with some countries gaining in agricultural productivity and others losing. Some current predictions are that countries located in northern latitudes will experience increases in precipitation in addition to increases in temperature, and the climatic zone suitable for a particular crop or ecosystem will shift polewards.

Consequently, this will have the effect of enhancing crop yields in the northern regions of the former

Soviet Union, Canada, and Europe (IPCC, 1990; Rosenzweig and Parry, 1993), whereas the cereal-growing belts of North America might shift northwards by several hundred kilometres for every centigrade degree rise in temperature. The predicted yield increases in these higher latitude regions are due primarily to a lengthening of the growing season and the mitigation of negative cold weather effects on plant growth (Rosenzweig and Parry, 1993).

Other studies predict that an increase in precipitation will also occur in the southern middle latitude countries (eg. parts of Latin America, Northern Africa, and Middle India), which would also enhance crop yields (IPCC, 1990). On the other hand, climate change is expected to have negative effects on crop and livestock productivity in northern middle latitude countries like the U.S., Western Europe, and most of Canada's currently productive agricultural regions. This predicted result is due to a shortening of the growing period for the plant caused by an increased temperature; a decrease in water availability for the plant caused by a combination of increased evapotranspiration rates, losses in soil moisture, and (in some cases) decreases in precipitation; and lower vernalization. Two exceptions to these general findings are China and Japan, which may benefit from climate change in terms of enhanced agricultural productivity because much of their agriculture is located near coasts. Consequently, these two countries are not predicted to experience the interior continental drying that is predicted for many countries in the northern middle latitudes (Tobey, Reilly, and Kane, 1992)

In the humid tropics and monsoon climates, increased intensities of rainfall events and increased rainfall totals would increase leaching rates in well-drained soils with high infiltration rates, and would cause temporary flooding or water saturation, hence reduced organic matter decomposition, in many soils in level or depressional sites. This may affect a significant proportion of especially the better soils in Sub-Saharan Africa, for example. They would also give rise to greater amounts and frequency of runoff on soils in sloping terrain, with sedimentation downslope and, worse, downstream. Locally, there would be increased chances of mass movement in the form of landslides or mudflows in certain soft sedimentary materials.

In subtropical and other subhumid or semi-arid areas, the increased productivity and water use efficiency due to higher CO_2 would tend to increase ground cover, counteracting the effects of higher temperatures. Much less rainfall locally could lead to less dry matter production and in due course, lower soil organic matter contents. Periodic leaching during high intensity rainfall with less standing vegetation could desalinize some soils in well-drained sites, cause increased runoff in others, and lead to soil salinization in high groundwater table.

Higher temperatures particularly in arid conditions entail a higher evaporative demand. In temperate climates minor increases in rainfall totals would be expected to be taken up by increased evapotranspiration of vegetation or crops at the expected higher temperatures.

In boreal climates, the gradual disappearance of a large extent of permafrost and the reduction of frost periods in extensive belts adjoining former permafrost are expected to improve the internal drainage of soils in vast areas with probable increases in leaching rates.

3.2 Overall Effects on Agricultural Soil

The soil is a complex and dynamic system, consisting of a solid phase (both mineral and organic, particulate and amorphous), a liquid phase (water and solutes), and a gaseous phase (air with associated water vapor, often enriched with carbon dioxide and sometimes with methane as well). The soil system responds to short term events such as the episodic infiltration of rainfall and also undergoes long term processes such as physical and chemical weathering. The main potential changes in soil-forming factors directly resulting from global change would be in organic matter supply from biomass, soil temperature regime, and soil hydrology, the latter because of shifts in rainfall zones as well as changes in potential evapotranspiration. Soil changes because of potential rise in sea level resulting from a net reduction in Antarctic ice cap volume and ocean warming is yet another matter of concern.

The quantitative evaluation of the predicted climate change on soil conditions is difficult, due not only to the uncertainties in the forecasts but also to the complex, interactive influences of hydrological regime, vegetation, and land use. Therefore only rough, qualitative estimations may be made and only general conclusions may be drawn at present.

Higher temperatures, along with changes in soil moisture, will lead to a wide range of soil and plant responses to global climate change. The physiological effects of increased CO_2 on plants may also have significant consequences on soil organic matter, which is in itself a major sink in the global carbon cycle. Thus, soils will respond to climate change in complex ways. The overall outcome will depend on numerous processes with often opposing effects. Changes in the soil are also likely to depend on topography, specific soil composition and properties, and crop or vegetation cover, all of which vary from place to place. Changing climate is likely to create climate-soil patterns that have not previously been observed in particular locales.

In general, warmer temperatures tend to hasten the chemical processes that affect soil fertility. The most important process is probably the accelerated decomposition of organic matter, which releases nutrients in the short run but may reduce soil ferility in the long run. In some cases, these decomposition losses may be balanced by increased carbon fixation of crops and vegetation and, hence, in a greater accumulation of organic matter residues. The net effect - the long term depletion or accretion of carbon storage of the soil - is hard to predict (C. Rosenzweig & D. Hillel, 1998). The biggest single change in soils expected as a result of these postulated forcing changes would be a gradual improvement in fertility and physical conditions of soils in humid and subhumid climates. Another major change would be the poleward retreat of the permafrost boundary. Other widespread changes would be in degree rather than in kind. Certain tropical soils with low physico-chemical activity, such as in the Amazon region, may undergo a radical change from one major soil-forming process to another.

3.2.1. Soil Erosion and Sediment Transport

Climate change will affect soils in a terrain, because their erosion potential will alter with changes in plant cover, rainfall and wind. The associated changes in primary production will also result in changes of organic material inputs to the soil. Soil degradation ranges from soil loss via erosion, through chemical depletion, to water logging from irrigation systems or solute accumulation. One sixth of the world's usable land has already been degraded by water or wind erosion. Large quantities of fertile soils are lost due to soil erosion, which is due to inappropriate management of agricultural land. The severity, frequency and extent of erosion will certainly be altered by changes in rainfall amount and intensity, and by changes in wind. Soil erosion will worsen and the availability of nutrients will be reduced with climate change as the calcium cycle will be modified.

One analysis of global soil erosion estimates that, depending on the region, top soil is currently being lost 16 to 300 times faster than it can be replaced. Soil-making processes are notoriously low, requiring from 200 to 1000 years to form 2.5 centimeters of topsoil under normal agricultural conditions. One 1994 study estimated that soil degradation between 1945 and 1990 lowered world food production some 17% (World Resources 1998-99). Regional studies have localized these losses. In Europe about 35% of the farmland in the Mediterranean region experiences erosion of between 20 and 30 tonnes per hectare per year. About 300 million tonnes of productive sediment are lost each year from agricultural land. In the UK it has been estimated that a loss of 12 tonnes of soil per hectare per year could reduce yield by 8%. In Africa, production losses from soil erosion alone are estimated at just over 8%. Data from several different studies indicate that the decline in productivity resulting from soil degradation may exceed 20% in a number of Asian and Middle Eastern countries. These losses are predicted to worsen as soil degradation continues (World Resources 1998-99).

In areas where climate change brings higher precipitation (and more precipitation falling as rain rather than snow), erosion should increase. Where precipitation becomes lower, the rate of erosion should fall. However, soil surface desiccation might make cultivated land more vulnerable to water and wind erosion, especially where the surface is devoid of vegetative cover and is pulverized by cultivation.

Such conditions could generate "dust bowl" effects in some regions. The hazard of water erosion might also grow worse, as sudden -albeit infrequent- rainstorms strike at the soil (C. Rosenzweig & D. Hillel, 1998).

Increased water erosion in the humid tropics is likely both as a result of land-use change and climatic change (notably changes in rainfall, especially storm profiles). Wind erosion is a potentially serious problem in many parts of the world. However, the phenomenon is most relevant in semi-arid areas, not necessarily in the geographical tropics. The forcing factors which exacerbate wind erosion include both changes in land use and climate. As with water erosion, land use change is the major issue at present, with increased population pressure accelerating the problem. Climate may also play a role; for example, a change in rainfall in the Sahelian region may cause a shift in the northern limit of land that can be used for agriculture.

The enhancement of soil erosion and desertification because of global warming represents the most incumbent ecological danger to mankind. Since soil organic matter accumulates in soils not only by ionic processes but also by weak bonding mechanisms such as hydrogen and hydrophobic bonding, the flocculation of soil aggregates can be achieved by using exogenous humic substances in soil management practices. Addition of humic substances may decrease runoff erosion by 40% in fragile soils while increasing soil capacity of moisture storage.

3.2.2 More Saline Soils

The most rapid processes of chemical or mineralogical change under changing external conditions would be loss of salts and nutrient cations where leaching increases, and salinization where net upward water movement occurs because of increased evapotranspiration or decreased rainfall or irrigation water supply. Salinization is a serious problem in the southern part of Europe. In the heavily irrigated areas for intensified agriculture, waterlogging and the secondary salinization of poorly drained soils are common occurrences.

In saline conditions, crop plants are continuously under osmotic stress as a result of high solute content in the rooting medium. Furthermore, the high concentrations of specific ions may cause toxic reactions. The majority of crop plants are sensitive to saline conditions, responding with reduced yields or, in extreme conditions, in total crop failure.

The impacts of global sea-level rise on coastal zones will vary from region to region because of local factors such as land subsidence, susceptibility to coastal erosion or sedimentation, varying tidal ranges, and cyclonicity. Sea-level rise will cause saltwater intrusion and rising water tables in agricultural soils located near coastlines. The deltas of major rivers are often extensively used for agriculture. In areas that already suffer from poor drainage (e.g. Bangladesh, China, Egypt, Indonesia, the Netherlands, and, in the United States, Louisiana and California), agriculture in coastal areas could become increasingly difficult to sustain.

3.2.3 Permanently Flooded Areas

In Bangladesh, the monsoon rains cause the rivers to flood each year. These floods are a normal part of life and help to renew the fertility of the soil. In recent years, however, the floods have become much more severe due to the clearance of forests in the Himalayas for fuelwood, farmland and logging. These floods have caused serious damage and loss of life. Severe flooding is also a problem in India. Each year over a million US $ are spent on river defence to control flooding. As a result of flooding millions of acres of land are destroyed, and millions of tonnes of rice and wheat crops are lost.

The major low-lying river deltas of southeast Asia are among the regions most vulnerable to sea level rise. These areas support extensive rice cultivation areas that face permanent flooding by even a small rise in sea level. A substantial percentage of rice paddies in low lying areas of southeast and east Asia will be vulnerable to anticipated sea-level rise following climate change.

3.2.4 Soil Organic Matter

Soil organic matter (SOM) is an important component of both managed and unmanaged terrestrial ecosystems. It is a major world natural resource and constitutes a carbon pool three times larger than that of the atmospheric pool. It is a key element of global change research for several reasons.

Firstly, it is important as both a driver of, and response variable to, climate change. Changes in temperature and water regimes influence SOM dynamics directly, through microbial processes, which in turn result in feedbacks to the physical climate system.

Secondly, enhanced CO_2 will affect net primary production which will potentially increase carbon inputs to the soil. It will also affect the chemical composition of plant residues and alter allocation to roots and root exudates.

In general, warmer temperatures tend to hasten the chemical processes that affect soil fertility. The most important process is probably the accelerated decomposition of organic matter, which releases nutrients in the short run but may reduce soil fertility in the long run. In some cases, these decomposition losses may be balanced by increased carbon fixation of crops and vegetation and, hence, in a greater accumulation of organic matter residues.

The net effect (the long-term depletion or accretion of carbon storage of the soil) is hard to predict, although such prediction is an important task since soil organic matter is a major reservoir in the global carbon cycle. While the physiological effects of increased atmospheric CO_2 on plants may add organic matter to the soil, warmer temperatures may accelerate its decomposition. The enhanced potential growth in a CO_2 enriched atmosphere may require additional application of fertilizers, since cycling of nutrients is likely to be accelerated with warmer temperatures. The fixation of atmospheric nitrogen by symbiotic bacteria will tend to increase with the greater root biomass of the CO_2 enriched crop. However, both biomass accumulation of crop roots and decomposition of organic matter will be suppressed if temperature risk is excessive or if soil moisture is limiting. It has been estimated that a 3% warming would cause an 11% decrease in SOM in the upper 30 cm of 'average' soils in the temperate zone (Buol et al, 1990).

3.2.5 Water Contamination

Water pollution is a worldwide problem. Waste from factories, farms, and cities is poisoning rivers and seeping into groundwater. Lakes are particularly at risk as they allow pollutants to build up. As a result of extensive irrigation, the ion content of river runoff changes. Salt removal from the irrigated massifs has exceeded that from land in areas of river runoff formation, so the inflow of salts to large lakes has increased. Coastlines and shallow seas are particularly vulnerable.

Climate change can cause a change in the level of mineralization due to water evaporation and salt accumulation. Mineralization of drainage runoff from irrigated massifs is increased. A significant part of drainage runoff is discharged to rivers, leading to increased river-water mineralization.

A coastal aquifer is bounded on at least one side by an extensive salt water body -a lagoon, a sea, or an ocean. Due to the direct contact between the freshwater in the aquifer and the saltwater body, coastal aquifers are vulnerable to encroachment of saline water and consequent degradation of water quality, which may affect human welfare and agricultural production. Freshwater is rendered marginal for human consumption if it is contaminated with sea water at the 2 to 3% level, and it becomes unfit for human use at the 5% level (C. Rosenzweig &D. Hillel, 1998).

As the recycling of waste water gains importance in the future, the problem of water quality will become yet more acute. Water quality tends to deteriorate under conditions of low flows and higher water temperatures, which are predicted for arid areas. In such areas, the impact of climate change on water quality may be especially significant.

3.3 Carbon Dioxide as a Crop Fertilizer

Changes in atmospheric CO_2 concentration may lead to changed soil organic matter quantity and type. In particular it may lead to changes in the amounts of photosynthate allocated below ground.

The predicted effect of climate change on crop yields depends critically upon whether or not the so called CO_2 'fertilizer effect' is assumed. The CO_2 'fertilizer effect' refers to an enhancement in crop yields due to elevated atmospheric CO_2, which increases rates of net photosynthesis and reduces stomatal openings, resulting in increased water use efficiency by the plant. CO_2 is an essential plant 'nutrient' in addition to light, suitable temperature, water and chemical elements such as N, P and K, and is currently in short supply. Higher concentrations of CO_2 due to increased use of fossil fuels, deforestation, and biomass burning, can have a positive influence on photosynthesis. For example, Rosenzweig and Parry (1993) report a world average decrease in yields for wheat, rice, maize, and soybeans for three climate scenarios they considered when a CO_2 'fertilizer effect' is not assumed. World average wheat yields would decline by as much as 33%, rice yields by as much as 25%, maize yields by as much as 31%, and soybean yields by as much as 57% under climate change.

On the other hand, when a CO_2 'fertilizer effect' is assumed, world average crop yields do not decline as much, or actually increase in several cases, under the climate change scenarios. In this situation, the impact of three climate change scenarios on world average wheat, rice, maize, and soybean yields range from -13% to 11% (wheat), -5% to -2% (rice), -24% to -15% (maize), -33 to 16% (soybean).

Other studies (e.g. Crosson, 1993; Adams et al, 1990) produce the same conclusion: that the assumption about CO_2 fertilization has a major influence on the impact of climate change on crop yields. In fact, the general result from these studies is that crop yields decrease under climate warming when there is no CO_2 fertilization, but that these decreases can be largely offset by assuming a positive CO_2 fertilization effect.

Recently, some have questioned the widely held belief that there will be a large CO_2 'fertilizer effect' accompanying climate change. Since there is debate over the magnitude of potentially beneficial effect, it has been recommended (Drennen and Kaiser, 1993) that research on the magnitude of the CO_2 'fertilizer effect' be one of the top priorities for future work on agricultural impacts of climate change.

3.4 Changes in the Length of the Growing Season

One consequence of the induced warming that will clearly benefit agriculture in the mid and higher latitudes is the lengthening of the potential growing season, usually defined as the period from the last frost in spring to the first frost in autumn. A longer potential growing season will allow earlier planting of crops in spring, hastened growth, and earlier maturation and harvesting. Consequently, multiple cropping (i.e., the planting of two or more crops in succession during the same season) may become possible. Multiple cropping is contingent on having sufficient water for two entire crops. Perennial crops such as alfalfa would also benefit from an extended growing season (C. Rosenzweig & D. Hillel, 1998).

For temperate zone agriculture, and in most of the northern and southern hemispheres beyond the tropics, it may be expected, but not guaranteed, that a warmer climate will lead to an increase in the length of the frost-free period, irrespective of altitude or latitude. This should also hold for agricultural enterprises in the mountainous areas of the tropics. The correlations between temperature and the length of the growing season may also mean that with warming there will be a gradual shift northward of the northern boundary for such crops as winter wheat and corn in north America, Europe and Asia. A comparable shift would be southward in the southern hemisphere. Similarly, the risk of freezing temperatures in Florida, Texas and California in the United States may be reduced under the climatic regimes of a global warming. The same would also hold for southern Europe, all Mediterranean countries, subtropical parts of Asia, Africa, and the countries of the southern Hemisphere. Crops could be planted earlier and harvest periods extended. This is assuming that a CO_2 induced warming would not increase climate variability and the riks to agricultural production. Other constraints on shifts in crop zonation include soil fertility, availability of water and technology, willingness of farmers to change crops, and sufficiency of product demand (i.e. marketing opportunities).

3.5 Pests and Weeds

Pests and diseases often dictate the success or failure of a crop, and weed encroachment is a common reason to abandon a site in shifting cultivation systems. As new varieties and crops are introduced in a given site, pest populations and the incidence of disease can rise rapidly, owing to life cycles and the ability to migrate. On the other hand, pests, diseases and weeds of existing crops may occur as the pest populations respond to changed environmental parameters. In either case, pests, diseases and weeds are likely to be early indicators of global change. One of the first noticeable effects of global change may be changes in agronomic pests and weeds. This is because global change will potentially affect the pest/weed-host relationship in one (or more) of three ways: by affecting the pest/weed population; by affecting the host population; and by affecting the pest/weed-host interaction. It is hypothesized that the net effect will manifest in one of several ways: (i) pest/weeds currently of minor significance may become key thereby causing serious losses; (ii) the distribution and intensity of current key pests/weeds may be affected, leading to changed effects on yield and also on mitigation techniques such as pesticides and integrated pest management; and (iii) the competitive abilities in weed-plant interactions may be affected through changes in ecophysiology.

Temperature patterns, rainfall or humidity and season length all have an effect on the development and distribution of pests and diseases (Melugin Coakley and Scherm 1996). Especially winter temperatures are important for survival of pest insects. Studies have shown that increased temperatures accelerate the development of individuals and reduce the time to reproductive maturity (Morgan 1996). Such earlier reproduction will lead to a rapid increase in pest organisms, and a more frequent development of epidemics. Also weed populations or ephemeral plant species may change in frequency and noxious weeds may become more common (Wilson 1996). The competitive ability of C_4 plants will be strengthened because of a rise in temperature and due to dryer conditions, but C_3 species will gain more from the higher CO_2 concentrations. The outcome of such complex interactions is uncertain, especially because of the influence of extreme events.

Pest-crop interactions will be directly affected by rising CO_2 levels through alteration of host-plant attributes such as C:N ratios and secondary plant chemistry, and through indirect modifications in patterns of stomatal opening, leaf water content, and leaf temperature. The combination of direct CO_2 effects on plant growth rates and change in average and extreme environmental conditions will have major impacts on pathogens and pest animals, particularly insects. In addition, rising CO_2 levels are likely to change competitive interactions between crops and weeds, for example by altering plant growth rates and allocation of above -and below- ground mass. Climate change is likely to cause a spread of tropical and sub-tropical species into temperate areas and to increase the numbers of many temperate species currently limited by low temperatures at high latitudes. The potential expansion of geographical ranges of pest species will be disruptive to quarantine barriers and is likely to result in increased costs to agriculture in previously pest-free areas. Similarly, an increase in temperature will lead to more opportunity for population growth in areas already affected by a pest.

Pests, diseases and weeds cause significant impacts on the world’s food production under current climatic conditions. Current losses caused by pests, diseases and weeds to the harvests of the world’s four most important crops are estimated by IGBP (Science No 1) at 36% on average of the world production (Maize 34%, Rice 44%, Wheat 30% and Potatoes 36%).

3.6 Desertification

Desertification threatens over a third of the world’s land surface. Severe deterioration and loss of soil can turn productive land into desert. Every year an area the size of the United Kingdom is either lost or severely degraded. The situation is becoming critical especially in the Sahel, the Andes and parts of south Asia.

Desertification occurs when productive land in arid, semi-arid, or sub-humid dryland regions is degraded by human activities and by climate variations such as prolonged drought. Although human activity is the main cause of desertification, global climate change may in turn accelerate desertification if higher temperatures increase evaporation or if rainfall decreases.

The occurrence of erosion and desertification is largely affected by intensification of agriculture in response to afforestation, ploughing of untilled land, burning of pastures and mulch, overgrazing, inadequate tillage practice, use of very heavy machinery and high usage of herbicides. Desertification often begins when people decide or are forced to use land in dry areas too intensively. Overcultivation, overgrazing, and the clearance of trees combine to degrade the soil.

Southern Europe has an increasing risk of desertification through soil erosion. This is partly due to changing soil and climatic conditions as rainfall will be diminished overall but become more torrential in small bursts. Once desertification is started, natural factors, such as drought accelerate the process.

The Global Climate Models suggest that in general the potential evapotranspiration will increase to cause a significant increase in soil moisture deficits. A major problem is associated with the probable deterioration of soil structure and the consequent unbalance of the partitioning of rainfall between infiltration and runoff. In aridic conditions the result will be soil desertification (Piccolo, 1996) .

Mick Kelly and Mike Hulme address the complex and often uncertain links between climate change, prolonged aridification or desiccation, and desertification. They pay particular attention to the case of the African Sahel. The authors are staff members of the Climatic Research Unit at the University of East Anglia (Norwich, UK).

The definition of desertification adopted by the United Nations Conference on Environment and Development in 1992 is degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities. This definition cites climate variation as a direct causal factor and it implicitly links climate change and the assessment of the extent of desertification. Since arid, semi-arid and sub-humid areas are climatically defined, any change in climate which results in an expansion or contraction of these areas will alter the extent of the area in which desertification can be considered to occur. For example, if an arid area converts to hyper-arid because of climate change, then the area in which desertification may occur will decrease. Hyper-arid areas are not included in the accepted definition. If a humid area converts to sub-humid, then the potential area within which desertification may occur will increase.

Determining the precise contribution of climate variation to the problem of desertification is not, however, an easy matter. Climate change does alter the frequency and severity of drought in various parts of the world and can cause desiccation. It does not necessarily follow, though, that drought and desiccation will, by themselves, induce, or even contribute to, desertification in dryland regions. Whether or not this occurs depends on the nature of resource management in these areas. Against a backdrop of management failure, climate change can certainly aggravate dryland degradation.

Separating out the interrelated impacts of climatic and human factors may be difficult but some progress has been made. For example, a satellite index of active vegetative cover for the Sahara has been derived by Tucker and his colleagues at the NASA Space Flight Center in Maryland. The index reveals marked interannual variations in the extent and quality of surface vegetation in this dryland area. A substantial proportion of this variation is attributable to climate effects, specifically rainfall variations.
Removing this component reveals a progressive increase of 41,000 km^2 a year in the area of the Sahara Desert during the 1980s.This trend could be the result of the cumulative impact of a series of dry years on vegetation recovery. Alternatively, it may well be due to deterioration in vegetation cover caused by human activity. Identifying the relative role of these factors in order to identify the most appropriate response is a pressing challenge.

The assessment is complicated by the fact that desertification itself may cause climate change. By modifying surface characteristics, dryland degradation can lead to reductions in surface soil moisture and so make more energy available to increase air temperature in the areas most afected. Varying degrees of uncertainty surround the linkages between climate change and desertification and desiccation.

Nevertheless, uncertainty should not be allowed to obscure the fact that there are intrinsic links that cannot be ignored.

3.7 Melting of Glaciers and sea level rise

An important source of evidence on climate warming and its effects, is the relatively firm data indicating that sea level has been rising at a rate of 1 to 2 mm per year for the last 100 years. The IPCC's central estimate is that, over the past century, ocean thermal expansion from warming contributed 4 cm to sea level, melting glaciers and small ice caps 4 cm, melting of the Greenland ice sheet 2.5 cm, and the Antarctic zero, for a total rise of 10.5 cm. Permafrost, which currently underlies 20-25% of the land mass of the Northern Hemisphere, could experience significant degradation within the next 40 to 50 years.

The IPPC (1996) has predicted that continuation of current trace gas and aerosol emission rates will cause mean sea level to rise at the rate of about 2 to about 9 cm per decade in the coming century, with a 'best guess' of about 5 cm per decade. Such a rate of sea-level rise could result in a total rise of 20 cm by the year 2050 and of about 50 cm by the 2100. This would render some island countries uninhabitable, displace tens of millions of people, seriously threaten low-lying urban areas, food productive land, contaminate fresh water supplies and change coastlines. All of these impacts would be exacerbated if droughts and storms become more severe. However, the major impacts of sea level rise would affect agriculture in deltaic nations such as Bangladesh, where a large part of the agricultural land could be inundated or eroded. Although important for localized regions, it would be relatively insignificant on a worlwide basis compared with other projected impacts of global warming on agricultural production.

3.8 Mutual Impacts between Climate Change and Agriculture

The impact on emissions from the agricultural sector is unclear. An analysis by Duxbury and Mosier (1993) concludes that agriculture contributes between 16-31% of the total of anthropogenic contributions to climate change. The main sources of pollution are the burning of agricultural waste, or of crops in the field and large intensive livestock units. Depending on soil type and fertilization, the nitrogen in the dung and urine of grazing cattle contributes 20-40% of nitrous oxide emissions from agricultural land; methane is also emitted by cattle and other ruminants; nitrous oxide and methane are of course both greenhouse gases.

Methane is the second most important greenhouse gas after CO_2. EU suported research has studied methane over Europe and the Atlantic.The experiments show that dominant (70-75%) west European sources are biogenic (e.g. cows, biological effects of human activities- landfills, sewage, etc.). Even if these estimates overstate the importance of agricultural emissions, the agricultural sector should not avoid scrutiny in the search for ways to minimize greenhouse gas emissions.

The goal for CO_2 reductions from the agricultural sector should be to make sure that land is used as efficiently as possible, thereby maximizing the preservation of non-cultivated areas, such as forests. This goal is particularly important in light of predictions which suggest that the area of agricultural land could increase by 60% by 2025 (IPCC, 1992b). Such an increase could result in releases of soil carbon of the magnitude of 5-10 years of current fossil fuel emissions. Further on cultivated lands, practices should aim to limit soil erosion, through minimization of tillage practices, and other conservation techniques. Another major goal should be to slow the current rate of deforestation and forest degradation.

Concerning methane, waste management practices should strive to ensure aerobic conditions at all times to minimize potential CH_4 releases. Such practices include minimizing the lagooning of waste, prompt application of wastes as fertilizer on fields, and the use of waste as a fuel source. Given the importance of rice in many cultures, it is unrealistic to expect countries such as China to reduce or curtail rice production. Instead research needs to continue on minimizing CH_4 emissions from flooded paddies, possibly through the selection and development of cultivars, nitrogen source and placement, the use of nitrification inhibitors and changes in the nutrient and water management practices.

Reducing N_2O emissions from the agricultural sector requires improved nitrogen management by paying closer attention to the use and management of fertilizer techniques, greater emphasis on biological nitrogen fixation, more timely applications and placement through the use of the GPS and the use of nitrogen sources that minimize N_2O emissions. (S. W. Wittwer, 1995)

Perhaps the thorniest problem with attempting to reduce agricultural emissions is verification of claimed emissions reductions. Instead of attempting to negotiate commitments that include the option of specifically reducing agricultural emissions, future agreements should focus on agricultural management practices, such as aerobic spreading of the wastes on fields or the installation of CH_4 collection systems on waste lagoons.

3.9 Net Effect on Crops

In the present, although total yields continue to increase on a global basis, there is a disturbing decline in the rate of yield growth. If such a slowdown persists, it could prevent production levels from rising as much as is needed in the next few decades. For wheat, yield growth rates slid from 2.92% per year for the period from 1961 to 1979 to 1.78% for the period from 1980 to 1997. For maize, the rates sliped from 2.88% to 1.29% during the same period. For paddy rice, yield growth rates have remained stable at 1.95%. Yet the demand for all cereals is expected to rise substantially in the next two decades. (World Resources, 1998-99)

The potential impacts of climate change on agriculture are highly uncertain. The large number of studies conducted over the past few years for many different sites across the world show few robust conclusions of the magnitude or direction of impact. The robust conclusion that does emerge from such studies is that climate change has the potential to change significantly the productivity of agriculture at most locations. Some currently highly productive areas may become less productive. Some currently marginal areas may substantially benefit while others may become unproductive. Crop yield studies show regional variations of +20, 30 or more per cent in some areas or equal size losses in other areas.

Table 4.1 summarizes the results of the large number of studies of the impact of climate change on potential crop production. While the table does not provide the detail on the range of specific studies, methods and climate scenarios evaluated, it provides an indication of the wide range of estimates. The general conclusion of global studies, that tropical areas may more likely suffer negative consequences, is partly supported by the results in the table. For example, Latin America and Africa show primarily negative impacts. However, very few studies have been conducted in these regions. For Europe, the United States and Canada, and for Asia (including China) and the Pacific Rim, where many more studies have been conducted, the results generally range from severe negative effects (-60, -70%, or complete crop failure) to equally large potential yield increases. The wide ranges of estimates are due to several, as yet unresolved, factors. Apart from how or whether the CO_2 effect on crops is included in the simulation, these factors -varying climate scenarios, wide variation across sites within a region, how genetic variability across known crop varieties is addressed within the crop-response-modelling approach, and differences across impact methodologies particularly in how different methods address the capability of farmers to adapt- appear to be of roughly equal magnitude in explaining the wide range of estimates.

A climate crop model based on the FAO crop-suitability methodology has been used to test potential change in yield and distribution of major crops under one GCM scenario (Cramer and Solomon, 1993; Leemans and Solomon, 1993). These studies have indicated large differences in regional response. Only high-latitude regions appear to benefit consistently from a climatic change due to projected longer growing periods and increased productivity. Other regions either do not benefit significantly or lose productivity. Potential agricultural declines are due primarily to regional differences in moisture availability.

Combined biophysical and economic analyses suggest that the effects of climate change on global agricultural production will depend on the magnitude of the change, the realization of potential physiological effects of CO_2 enrichment on crop growth and water use (such as have been found in experimental settings), and the extent to which appropriate adaptive measures are implemented. The last depends to a large degree on the costs of the adaptive measures. While uncertainties yet exist regarding the direction of change in global agricultural production in various regions, aggregate effects have been generally predicted to be small to moderate. (Kane et al. 1992; Reilly and Hohmann, 1993; Reilly et al. 1994; Rosenzweig and Parry, 1994). The small aggregate response (either positive or negative) occurs because reduced production in some aeas is likely to be balanced by gains in other areas (Kane et al., 1992).

In the case of climate change without the beneficial CO_2 effects on crop yields, world cereal production is predicted to fall by 11 to 20%. In contrast, inclusion of the direct CO_2 effects obviates most of that fall, to between 1 and 8%. The overall world production changes however, mask a disparity in response to climate change between developed and developing countries.

Globally, both minor and major levels of adaptation can help restore world production levels (especially when CO_2 physiological effects are included), compared to climate change scenarios with no adaptation. With minor adaptation, averaged global cereal production is predicted to diminish by up to 160 mmt (0 to -5%) from the reference scenario projection of 3,286 mmt. With major adaptations, however, global cereal production may range from a slight increase of 30 mmt to a slight decrease of 80 mmt (i.e., from +1% to -2.5%). Level 1 adaptation largely offsets the negative climate change effects on yields in developed countries. In these regions, cereal production is calculated to rise by 4 to 14% over the reference scenario.

However, developing countries are predicted to benefit little from this level of adaptation, and may experience a negative change of -9% to -12% in cereal production. More intensive adaptation may effectively eliminate the overall global reduction of cereal yields foreseen (Rosenzweig and Hillel, 1998).

In 1989, the U.S. Environmental Protection Agency commissioned a 3-year study to assess the potential impacts of climate change on world food supply, trade and risk of hunger (Fischer et al., 1994; Rosensweig and Parry, 1994; Rosenzweig and Iglesias, 1994; Rosenzweig et al., 1995) Agricultural scientists from 18 countries (Argentina, Australia, Bangladesh, Brazil, Canada, China, Egypt, France, India, Japan, Mexico, Pakistan, Philippines, Thailand, Uruguay, United States, Russia, and Zimbabwe) estimated potential changes in national grain crop yields using compatible crop models and three consistent climate change scenarios from three GMCs: the Goddard Institute for Space Studies, the Geophysical Fluid Dynamics Laboratory of the US, and the UK Meteorological Office models, projected to the year 2060, when atmospheric CO_2 is presumed to double over current levels. The crops modeled were wheat, rice, maize and soybeans. The crop models were run for current climatic conditions, for arbitrary changes in climate (+2 and +4^{0}C) increases in temperature and + or - 20% precipitation, and for climate conditions predicted by the GCMs for a double atmospheric CO_2 level. The photosynthetic ratios (555 ppm CO_2/330 ppm CO_2) for soybean, wheat and rice, and maize were 1.21, 1.17, and 1.06 respectively. Changes in stomatal resistance (sm) were set at 49.7/34.4 for C_3 crops and 87.4/55.8 for C_4 crops.

Results of this study, with the direct effects of CO_2, and precipitation held at current levels, revealed that average crop yields, weighted by natural production, showed a positive response to +2^{0}C warming, with yields of wheat and soybeans increased by 10 to 15% and rice and maize by 8%. Yields of all four crops turned negative at +4^{0}C warming. This indicated a threshold of compensation for the direct effects of CO_2 between 2 and 4^{0}C. Rice and soybeans were the most negatively affected.

The differences between countries in crop yield responses to climate change without the direct effects of CO_2 are primarily related to differences in current growing conditions. The crop modelling results showed that higher temperatures tend to shorten the growing period at all locations tested.

At low latitudes, however, crops are currently grown at higher temperatures, produce lower yields, and are nearer the limits of temperature tolerances for heat and water stress. Warming at low latitudes thus results in accelerated growing periods for crops and greater heat and water stress, resulting in greater yield decreases than at higher latitudes. In many mid- and high-latitude areas, where current temperature regimes are cooler, increased temperatures do not significantly increase stress levels. At some sites near the high-latitude boundaries of current agricultural production, increased temperatures can benefit crops.

Europe

For assessing the overall impact of climate change on agricultural production in Europe, relevant research has been conducted for the European Commission (EUR 17470 EN). The summary of results includes the following:

- The more physically realistic transient climate change scenarios result in enhanced positive impacts on agriculture in Europe relative to the original equilibrium scenarios because changes in climate associated with a given CO_2 concentration are less severe.

- The occurence of agriculturally significant extreme events is altered by relatively small changes in climate. The probability of exceeding crop-specific high temperature thresholds increases with climate change resulting in significantly higher risk of crop failure in parts of southern Europe. The length of the frost-free period increases enabling new crops with higher thermal requirements and lower frost tolerance to be cultivated in northern Europe.

- Understanding the effects of carbon dioxide and temperature on crop yield has improved through experimentation: elevated CO_2 concentrations cause beneficial effects on C_3 crops. The mean yield improvement at doubled CO_2 is 67% for onion, 23% for grapevine and 50% for wheat. Interactions with warmer temperatures and nutrient limitations reduce these increases in yield.

- The yields of C_3 crops such as vegetables, grapevine and wheat, generally increase with climate change due to large beneficial effects of CO_2 on photosynthesis. This compensates for the negative effects of warmer temperatures on yields which cause a reduction in the duration of crop development stages. In contrast, C_4 crops such as maize decrease due to limited benefit gained from CO_2 enrichment. Interactions with altered precipitation and increased evapotranspiration may affect the response (table 4.2).
- Current differences in crop productivity between northern and southern Europe are increased under climate change. The countries of northern Europe benefit by being able to grow a wider array of crops than are currently possible due to a warmer and longer growing season. Crops which are presently grown throughout Europe experience more positive impacts in northern Europe compared with southern Europe.
- The inter-annual variability of crop yields changes with mean climate change. In regions where crop production is affected by water shortages, such as in southern Europe, increases in the year-to-year variability of yields in addition to lower mean yields are predicted.
- Climatic variability may also change in the future in addition to the mean climate which would change crop yield responses. The inter-annual variability of yields is particularly sensitive to changes in climatic variability.

4. THE GEOGRAPHY OF CLIMATE CHANGE EFFECTS ON AGRICULTURE

4.1 The Most Vulnerable EU Regions

The Intergovernmental Panel on Climate Change (IPCC 1996) has defined agricultural vulnerability to climate change as the risk of negative consequences of climate change that are difficult to ameliorate through adaptive measures. Types of vulnerability include risk of large yield reductions that might result from small changes in climate, risk to farmers of profitability loss, risk of economic decline in regions that depend heavily on the farm sector, and risk of hunger for people with limited access to food or means to acquire it. Vulnerability can be defined at different scales, from the household level to the national, regional and global levels.

Western and southern Europe

Considerable work has been accomplished on agricultural climate change impacts in western Europe (e.g., Parry et al., 1988; U.K. Department of the Environment, 1991; Kenny et al., 1993). In general, modeling studies have suggested that simulated grain yields are likely to increase in the north, but to decrease in the Mediterranean area even with agronomic adaptations. The zone of maize production may extend as far as north as the UK and central Finland (Kenny and Harrison, 1992a).

Vegetable crops may expand in northern and western areas, but decline in southern Europe (Kenny et al., 1993; Olsen et al., 1993). Fruit production may experience winter chilling and loss of production in the south, where grapes in particular are likely to be affected (Kenny and Harrison, 1992b; Kenny et al., 1993). Growing water deficits in southern Europe will intensify the demand for irrigation (Iglesias and Minguez, 1996)

The inter-annual variability of crop yields changes with mean climate change. In regions where crop production is affected by water shortages increases in year-to-year variability of yields in addition to lower mean yields are predicted.

Southern Europe suffers from severe soil erosion, desertification, increasing risk of aridity, and forest fires. With climate becoming drier these phenomena will be intensified. Climatic variability experienced during recent years already led to dramatic situations of water shortages, erosion, land slides and harvest losses. These threats may be enhanced by even relatively small shifts of the general circulation systems of the atmosphere and the oceans. At present, there is evidence that climate changes will hinder rather than help the progress towards sustaining water supplies and agricultural productivity.

Drier winter conditions are the largest potential problem, but much depends on the changes in rainfall patterns. There is also evidence of decreasing rainfall in the Mediterranean basin.

In the Mediterranean region global warming will cause soil evapotranspiration to exceed rainfall thereby leading to an increased soil organic matter degradation. Higher temperature will cause mineralization of the humified organic carbon that is the essential cementing agent of permanent soil microaggregates and, hence, the main factor of soil physical quality. Physical soil degradation will cause a collapse of soil structure with consequent reduction of aggregates porosity and water infiltration rates.

France.

Dellecolle et al. (1994, 1995) reported that under both temperate and Mediterranean climates in France, winter cereal yields can be maintained under future climate conditions, provided that irrigation supply will not be limiting. Under temperate climate, maize yields may well increase, and maize production may shift northward. Under Mediterranean conditions, in contrast, the reduction of phase duration will entail a yield decrease, even under optimal irrigation. Adaptation simulations (change in planting date) produced only slight improvements in yields.

Italy.

Warmer and drier climates in south and central Italy could extend the cultivation range of olive and citrus to the north (Morettini, 1972; Le Houerou, 1992). Bindi et al. (1993) found that temperature increases and precipitation changes would generally lower yields of winter wheat in northern and central Italy if physiological effects of CO_2 are not taken into account. Rosenzweig et al. (1995) identified the Po valley, central Italy (Tuscany and Latium), the Apulean and Sicilian Plains as agricultural regions where integrated climate change impact studies would be especially useful.

Spain and Greece.

In Spain, summer irrigated crops as maize may go out of production due to yield reductions and lack of water availability for irrigation (Iglesias and Minguez, 1995, 1996). The authors suggest that effective irrigation scheduling can minimize water stress during sensitive development phases. For winter dryland crops such as wheat, productivity may increase significantly in some regions and wheat zonation may extend northward.

Kapetanaki and Rosenzweig (1996) have tested potential impacts on maize yields in central and northern Greece and found that while climate change scenarios generally predict decreases in maize yield, analyses of potential adaptations showed that climate change effects may be mitigated by means of earlier sowing dates and the use of varieties with longer growth periods or higher kernel-filling rates.

The Fennoscandian region and Alpine regions

High latitude systems have been identified as critical in the context of global change effects because of the likelihood of significant temperature change there, the substantial stocks of carbon and nutrients in soils, and the contrast in dominant life form across the boreal forest -tundra transition. The Arctic is a major store of soil carbon, an important contributor to greenhouse gases, and will be subject to major climate change in both absolute and relative terms.

There is evidence for significant climate warming over recent decades and the region's forecast increase of 0.5-1.0 ^{0}C per decade is not only the largest temperature rise globally but is high relative to the current ambient temperature. Such temperature changes will have an impact on, among others, soil biological processes.

A study on climate change impacts on forest resources in Finland (A. Talkkari, 1998), showed that tree species composition is likely to be altered under climate change. Especially in southern Finland, the proportion of Pendula birch in the growing stock may increase due to its competitive capacity under increasing temperature, while the proportions of Scots pine and Norway spruce may even decrease. In northern Finland, the growth potential of Scots pine may increase the volume of the growing stock even without a climate change. However, due to climate change, the volume of Norway spruce and Pendula birch may increase substantially in northern Finland. The simulations showed that at the country level the annual growth could increase, on average, by 21%, and the annual felling yield, on average, by 22%.

In Alpine regions, wherever there are steep mountain slopes, there is the possibility of landslides and avalanches. Sometimes heavy rain can make the earth unstable. In other cases erosion causes dangerous undercutting. Violent storms, fires, rockslides, and avalanches may increase. Severe rock falls are likely to multiply with the melting of permafrost, and avalanches will increase as warmer weather creates spring snow conditions. Even if storms do not increase in frequency, they may increase in intensity. Weather patterns could even develop monsoonal tendencies, with very heavy downpoors on exposed slopes leading to erosion and flooding. Erosion would be particularly bad if, as appears likely, forests become further weakened by drought, storms, and rising temperatures. A range of unpredictable disasters, such as the emptying of ice -or moraine-damned lakes (as happened near Salzburg in 1932 when an ice plug shifted), could also be expected.

Europe's mountains are particularly vulnerable to climate change. The intricate topography of mountain environments complicates weather patterns and confuses climate models, making it more difficult to project the specific impact of climate change on these regions. Nevertheless, it is clear that climate change will add to the current strong stresses on Europe's mountain areas, which are already threatened by pollution and population pressures. The recent warming trend is now producing symptoms such as reduced snowfall, retreating glaciers, and increased rock falls that can be expected to worsen with climate change.

It is assumed that forest ecosystems which have been exposed to atmospheric pollutants have acquired an increased sensibility for climatic extremes. Among the potential stress factors are late and early frost events, which do occur when trees have already lost most of (spring) or not yet acquired (autumn) their frost resistence. Low temperatures at higher altitudes are usually combined with high windspeeds, which make the situation even harsher.

Changes in the pattern of precipitation may have an even greater impact than rising temperatures. Because the Alps run east to west, they tend to block or deflect the southward flow of cold northern air. According to climate models, as the earth warms this tendency may increasingly cause a northward shift in the precipitation belts associated with the Intertropical Convergence Zone. While the Scandinavian mountains would become wetter, the Alps and Carpathians would become drier, particularly on their southern slopes.

A 10% decline in precipitation in the Alps plus a 1-2 degrees rise in temperature could produce 40-70% reduction in runoff. Mountains are the water tower for the plains below them. Because the mountains, and particularly the Alps, are the primary source for major rivers as the Rhine, Rhone, Po, and Danube, the impact of reduced mountain precipitation would be felt far beyond the mountainous regions themselves. One can expect that the development of the climate during the last 100 years and especially the latest rise in temperature during the eighties and nineties is going to exert some influence or stress on the European forest ecosystems. Possible consequences of a temperature increase in the Alps include a movement towards higher altitudes of the alpine-nival flora. (Environemnt and Climate Programme, European Commission). A temperature rise of 1 degree would result in a vertical shift of ecological zones by 150 metres, and a 3 degrees rise would give the Alps a climate much like that of today's Pyrenees. The result would be the disappearance of some 75% of the Alpine zone (2,200-2,900 metres) and the nival zone (2,900 metres and above). At least 150 plant species would be threatened or would disappear. Even in lower zones, many species may prove unable to adapt as their habitats migrate.

Forests typically take centuries to adapt to new conditions and so would be especially hard-hit. Sensitive stages in the life cycle of most tree species - including pollination, flower production, and seed germination- would be upset by climate change. Already, half of the mountain forests are sick or dying because of air pollution and other stresses. Warmer temperatures would encourage insects and biological pathogens that attack trees, killing or weakening them. Forest fires would increase, especially in over mature stands. A combination of weaker forests and stronger storms would cause more windfalls. The overall result would be widespread deforestation in the mountains of southern and central Europe.

Alpine agriculture is one economic sector that may benefit from global warming, although southern slopes may suffer from excessive dryness and fruit trees that depend on winter chilling to initiate or accelerate the flowering process may become less productive.

4.2 Former Soviet Union and Eastern Europe

Studies carried out on potential climate change impacts in Russia and other parts of the former Soviet Union include Menzhulin et al. (1995) and Sirotenko et al. (1991). Their results in general indicate a potential for agricultural regions to expand northward and for productivity to improve. Menzhulin et al. (1995) found that winter wheat should be able to replace spring wheat in many locations under warming conditions. Currently, many studies in Eastern Europe are under way through the U.S. Country Studies Program (1994) as reported in Dixon (1997).

4.3 Overview of Regional Vulnerabilities Worldwide

Regions of the world differ in the biophysical characteristics of their climate, soil, and water resources; in land-use patterns; and in the vulnerability of their agricultural systems to climate change. Any typology of vulnerable regions and impact categories should be based on connections between risks of climate change and existing environmental, economic and social conditions (Table 4.3) (Schmandt and Clarkson, 1992; IPCC, 1996). Vulnerability differences depend on such current conditions as poverty levels, air and water pollution, availability of agricultural credit, quality and versatility of research, and the rate of population growth.

4.3.1 Africa

In Africa local production of cereals cannot keep pace with population increase, and production of root and tuber crops is growing faster than that of the nutritionally more valuable cereals. Arable land growth lags behind population growth, which indicates some intensification of production. Sub-Saharan Africa is exceedingly diverse in climate, natural resources, and stage of development. Many of the agricultural zones of Africa suffer from periodic drought, among them the subhumid tropical zones, the humid equatorial highlands with bimodal rainfall, and the savanna regions, including the Sahel. Marked intraseasonal and interannual variability of rainfall creates a high risk environment for agriculture (Schulze et al., 1993). Crop growth in the humid, tropical zones suffers from acid soils (Hillel, 1991) and low solar radiation due to cloudiness.

Agriculture is a dominant activity in many of the countries in Sub-Saharan Africa. Smallholder farmers produce most of the local food supply. There are also large scale plantations and ranches that grow commercial crops such as sugarcane, rice, tea, coffee and cocoa, and that raise livestock. Countries with strong commercial agriculture include Kenya, Zimbabwe, and South Africa.

Despite the importance of agriculture in Africa, relatively few climate change impact studies have ben carried out. Some of the published studies include Zimbabwe (Muchena, 1994), South Africa (Schulze et al., 1993), Senegal (Downing, 1992), The Gambia (Jallow, 1996), and Kenya (Fischer and van Velthuizen, 1996). Magadza (1994) has examined the impacts of climate change on several sectors, including agriculture and water resources, in southern Africa, and he highlights the sensitivity of water resources, possible loss of important wetland habitat, and projected reduction in biodiversity. Rainfed agricultural systems would be adversely affected with consequent impact on food security. Hulme (1996) has explored potential impacts on natural and managed ecosystems in the Southern Africa Developemnt Region. (SADC).

Muchena (1994) found that the probability of obtaining an acceptable yield of maize, the most important food crop in Zimbabwe, decreased under 2^0C warming. Simulated maize yields indicated diminished yields, even when the positive physiological effects of higher atmospheric CO_2 were taken into account. Although Muchena's results suggested that farmers in Zimbabwe may be able to offset some of the yield losses by applying fertilizer and irrigation, such solutions may not be very realistic due to the high cost of inputs to farmers with limited financial resources. In Kenya, by contrast, crop zones may extend to higher altitudes, resulting in a net increase in productivity, although agricultural regions are predicted to shift (Fischer and van Velthuizen, 1996). Vulnerable groups in subhumid and semiarid regions are likely to be negatively affected nonetheless (Downing, 1992).

Fischer and van Velthuizen (1996) have conducted a detailed study of potential impacts of climate change on agricultural potential in Kenya. They found that the national level food productivity potential of Kenya may well increase with higher levels of atmospheric CO_2 and climate change induced increases in temperature. In particular, in central and western Kenya, temperature increases would result in expansion of cultivation since some higher altitude areas would become suitable for cropping. In the semiarid parts of Kenya, however, if warmer temperatures are not accompanied by higher precipitation, the impact on agricultural productivity could be severe. Thus, the authors conclude that even though the overall effects of climate change in Kenya may be positive, the impacts may intensify regional disparities.

The potential for increases in drought frequency and severity with climate change is of special concern for Sub-Saharan Africa, since droughts in the current climate cause severe disruptions to regional food supplies. Negative impacts of climate change would include exacerbated land degradation in the savanna zones, deforestation in more humid regions, and soil erosion. Schulze et al. (1993) emphasize the importance of intraseasonal and interannual variation of rainfall for crop yields in southern Africa. Sivakumar (1993) has documented that recent droughts had shortened the current crop growing seasons by 5 to 20 days.

4.3.2 Asia

Arid Western Asia

In Asia, the upper limit of available land has been reached in several countries, resulting in very high cropping intensities and a dominant role for irrigation. According to a study on the Aral Sea (Glazovsky, 1995), the situation is aggravated by the fact that environmental degradation is accompanied by a deterioration in economic and social conditions. Many of the problems of the Aral basin are typical of arid and semi-arid regions of the world.

Landscapes of arid and semi-arid regions are known to be very sensitive to global climatic changes and to tectonic events and other physical processes. Important changes have occured in practically all of the components of the environment in the Aral basin over the past 30 years: river runoff began to fall and decreased to approximately 4 Km^3 /year; the Aral sea area and volume decreased; the local climate changed; groundwater levels have fallen on non-irrigated land but have risen on irrigated land causing intensive soil salinization. Environmental deterioration together with climatic changes negatively affect agricultural production, including that on irrigated land, much of which becomes salinized. The productivity of irrigated land started to fall since 1988, cotton quality has deteriorated, total fodder reserves declined and the productivity of cereal-forb and forb meadows decreased threefold. Reserves of medicinal plants also decreased.

Temperate Asia

About 31% of the land is characterised by severe desertification, with productivity reduced by over 50%. Poor irrigation schemes are causing desertification in the southern states of the former USSR.

In East Asia, several climate change impact studies have shown that warming could expand the area suitable for agricultural production and increase potential rice yields. China has about 7% of the world's cultivated land, but supports more than one fourth of the world's population. China is the largest rice producer and consumer in the world. However, increasing population, spread of urbanization, lack of sufficient water resources, and environmental pollution, may hinder growth in China's agricultural productivity in the future. Jin et al. (1995) examined potential climate change effects on rice production in southern China and found that a rise of temperature will extend the northern limits for double-rice and tripple-rice cropping systems by 5 to 10^0 of latitude depending on the scenario. For paddy rice, adjusting planting dates ameliorated the negative effects of climate change on modeled yields in the northern part of the studied region, but not in the southern part. In climate change scenarios where precipitation decreased, the amount of water needed for full irrigation increased. The study by Matthews et al. (1995) also revealed that simulated rice yields in China tended to vary among regions and with GCM doubled CO_2 scenario (yield changes ranged from 14 to -38%).

Several climate change impact studies have been conducte in Japan, examining both major production areas and vulnerable regions. Uchijima (1987), Horie (1987), and Uchijima and Seino (1988) have shown that warming could expand the area suitable for agricultural production and increase potential rice yields. Seino (1995) found that adjustment of agricultural practices, such as advancing the planting date and applying supplemental irrigation, could adapt and even augment yields of rice, wheat and maize at most sites under doubled CO_2 climate change scenarios. The success of the adaptation measures, however, depends on the magnitude in the change of precipittion and the future improvement of irrigation systems.

Tropical Asia

Many parts of the humid tropics are characterised by land-use change, usually the conversion of forests to agricultural use. The result is severe flooding which is aggravated by climate change. Lowland regions risk to be permanently flooded following sea-level rise from the melting of glaciers. Salt-water intrusion and rising water tables in agricultural lands located near coastlines would ensue.

These same regions suffer already from tropical storms - typhoons- which have destructive power and which will get stronger with climate change.

In the tropics, increasing pressure on land is accelerating soil fertility loss, compaction through over-grazing and soil erosion, and essential soil biological processes are being severely disrupted. Superimposed on the immediate human pressures is the longer term complication of climate change, with an apparent trend of increasing frequency of drought in some semi-arid regions already being observed.

Societies in the tropics tend to be rather dependent on agriculture and therefore are vulnerable to climate change. Approximately 75% of the world's people live in the tropics, and two thirds of them rely on agriculture for their livelihood. With low levels of technology, land degradation, and rapid population growth, societies in some tropical regions may encounter increasing difficulty in providing food security even if climate does not change significantly.

The present social strucutres of some tropical countries may also exacerbate their vulnerability to climate change. Inequitable land tenure, high numbers of landless rural dwellers, low incomes, and high national debts worsen the negative impacts of climate variability. Growing numbers of people have no extra land, jobs, savings, or government assistance to see them through droughts or other climatic extremes. Moreover, when the economic system is oriented toward export rather than subsistence agriculture, climatic change may threaten a large part of the national economy and thus the ability to staple foodstuffs. Regions that cannot feed their populations depend on cereal imports (C. Rosenzweig & D. Hillel, 1998).

Agriculture is an important sector in south and southeast Asia. Rice is the leading food crop, although other crops, including wheat, soybeans and maize are raised in the drier regions. Root tuber, fruit, and vegetable crops are also grown. Plantation crops include tea, cocoa, coffee and rubber for export. The dominant system for growing rice is in irrigated fields (paddies). In fact, irrigation here covers a higher proportion (70%) of agricultural land than anywhere else in the world.

Qureshi and Iglesias (1994) used global climate models and dynamic crop growth models to estimate the potential agricultural effects of climate change in Pakistan. Under present climate conditions, wheat is under stress due to high temperatures and arid conditions. Projected climate change is projected to diminish wheat yields dramatically in the major areas of agricultural production, even under fully irrigated conditions. Decreases in simulated grain yields were caused primarily by temperature rises that shortened the life cycle of the crop, particularly the grain-filling period, thus exerting a strong negative effect on yields.

Studies of climate change impacts on wheat and sorghum production in India (Rao and Sinha, 1994) also indicated that yields would generally decrease, although responses varied by crop and season.

Bangladesh is vulnerable to many environmental hazards, including frequent floods, droughts, cyclones, and storm surges that damage life, property, and agricultural production. Karim et al. (1994) found that current rice production could be damaged under current climate change conditions as projected by GCMs.

A major study on climate change and rice has estimated the potential impacts of equilibrium doubled-CO_2 climate change scenarios in many countries in Asia (Matthews et al., 1995). This study found that simulated yield effects can vary widely (+30 to -38%) accross the region and for the different GCM scenarios.
Decreased rice yields were projected for low latitude countries, whereas increased yields were projected for higher latitudes. Such results suggest a possible shift in rice growing regions away from the equatorial regions to higher latitudes. Panicle sterility can be caused by higher temperature in many current rice varieties, and this study showed that this could be a critical factor in rice response to global warming scenarios.

Accross the entire region of south and southeast Asia there is concern about how climate change may affect El Niño Southern Oscillation events, since these play a key role in determining yearly agricultural production.

4.3.3 Oceania

The risk of tornadoes is getting stronger. Tornadoes are violent whirling storms associated with rain and thunderstorms, about 100 metres in width, and with only the most violent lasting longer than an hour. Wind speeds at the centre can reach over 300 Kph. At such high speed the tube of spinning air can cause loss of life and severe damage to property.

Australia

75% of Australia is at risk of desertification due to poor stock raising. In Australia, Baer et al. (1994) found that dryland wheat yields may increase in response to greater precipitation, but may be reduced if temperature increases are large. Rice yields are expected to decline slightly due to temperature increases.

The IPCC (1996) has summarized the following potential climate change agricultural effects in Australia: poleward shifts in production, varying impacts on wheat including changes in grain quality, likely inadequate chilling for stone and pome fruits reducing fruit quality, enhanced likelyhood of heat stress in livestock (particularly dairy and sheep), greater infestations of tropical and sub-tropical livestock parasites but possible decreases for other species, livestock improvement due to warmer and shorter winters, increased damage due to floods and soil erosion, more severe drought potential (with wheat and barley more sensitive than oats), changes in severity of outbreaks of downy mildew on grapevines and rust in wheat, and beneficial effects of elevated CO_2 on many agricultural crops.

New Zealand

Similarly, in New Zealand, climate change studies predict overall gains due to poleward and altitudinal shifts in production areas, more tropical and less temperate pasture regions, and the beneficial effects of CO_2 on growth (Campbell et al., 1995). Subtropical horticultural crops and maize may expand, but temperate crops such as apples and kiwi crops may lose critical vernalization periods (Salinger et al., 1994).

Small Island States

Some Pacific ocean islands are at risk of disappearance from permanent flooding due to sea level rise from higher precipitation and the melting of glaciers.

Few studies have been conducted on potential agricultural impacts in this area of the Pacific. Singh et al. (1990) have projected that crop yields might suffer from reduced solar radiation due to increased cloudiness, higher mean temperature leading to shorter growth duration and greater incidence of sterility, and both excess and limited water availability depending on changes in climate variability. Flooding could cause maize yield and production losses, while greater cloudiness and sea water intrusion could damage rice growing potentials.

4.3.4 Latin America

Relatively few agricultural climate change impact studies have been done in South America, despite the general importance of agriculture in most of this continent's economies.

In Latin America the increase in arable land is achieved only at a high ecological cost -deforestation- which may have direct relevance to climate change. Nearly a decade ago plans for major research campaigns in the South American rainforest emerged in several scientific communities in response to a widespread concern about the potential adverse effects of large-scale rainforest clearing. The Amazon basin is a major source of heat and water to the global atmosphere, and there is concern among climatologists about the effects large scale conversion of tropical rainforests might have on regional and global climates and on the carbon balance.

Regardless of Amazonia's contribution to global climate change, environmental change in this basin has acute, regional implications, especially for soil and water. Soil erosion is one of the most serious threats to the sustainability of agriculture, silviculture, and forestry in Amazonia. The need to protect the soil is a major reason why perennial crops, silviculture, and properly managed pastures are among the more viable options for rural development in areas already cleared. Soil erosion and associated loss of nutrients are contributing factors in the decision of many farmers to abandon their fields and clear a fresh plot from the forest. Soil erosion can also aggravate floods. Some unusually heavy floods along the Amazon in the mid 1970s raised speculation that deforestation in the foothills of the Andes was having a tangible impact downstream. Peru, the Honduras and Brazil suffer already from severe flooding resulting in extensive property damage and hundreds of deaths.

Concerning agricultural output, according to Sequeira et al. (1994), wheat and maize production in Brazil will tend to decline under climate change scenarios, but soybean production is likely to remain the same or increase. Adaptation strategies such as irrigation, changes in planting date, and increased nitrogen fertilization can evidently improve yields, but not enough to compensate entirely for the losses. Current climate variability due to El Niño Southern Oscillation events has a strong effect on many regions of south America, particularly northeast Brazil. If climate change brings shorter rainy seasons or increased frequency of years when the rainy season fails altogether, this region would suffer.

On the other hand, the Caribbean suffers from hurricanes which are tropical storms with violent winds and torrential rain doing terrible damage. Not only they can tear buildings apart, but the low pressure can create a surge of seawater that floods coastal areas. The torrential rain adds to these problems. Hurricanes will become stronger with global warming.

4.3.5 North America

Canada

The nation contributes significantly to international export markets, being the third largest wheat exporter in the world. While some climate impact assessment studies show the potential for positive response to climate change resulting from amelioration of cold limitations on the growing season, the wheat industry in the prairie region is considered to be vulnerable to climate change due to the drought-prone current climate and soil limitations of the region (Stewart, 1990; Brklacich and Smit, 1991; Singh and Stewart, 1991; Cohen et al., 1992).

Brklacich et al. (1994) estimated the effects of global climate change on wheat yields in the Canadian prairie and projected that spring wheat yields would decrease if temperature were to rise and the crop growing period were to become shorter. However, the positive physiological effects of CO_2 enrichment would likely compensate for those tendencies except under very hot and dry conditions.

USA

Topsoil is being lost faster than it is being formed in nearly half of the land area The prairies are particularly at risk from monoculture and overcropping. Apart from the West coast, which will be more humid than before and at the same time suffer from flooding through rise in the sea level, the rest of north

America will become drier than before leading to a sharp fall in grain crop yields.

Climate change will affect U.S. agriculture in many ways, most likely bringing regional shifts in production areas and increased demand for irrigation. Projected U.S. impacts depend strongly on the severity of climate change scenarios, in regard to both temperature and precipitation, as well as possible changes in climate variability. Studies tend to show worsening effects as temperatures approach the high end of the IPCC range of mean global warming (1.5 -4.5^{0}C) (These estimates have recently been reduced to 1-3.5^{0}C to better account for the effects of aerosols.)

Rosenzweig et al. (1994) considered the potential effects of global climate change on wheat, maize, and soybean production in the United States. Climate scenarios derived from three GCMs near the high end of the IPCC range for global mean temperature rise were used in combination with crop growth models to characterize yield and irrigation water demand changes of three main crops in major agricultural regions. Under the present management system, projected climate change caused simulated wheat, maize, and soybean yields to decrease at most sites even when the direct effects of CO_2 were included. These decreases were caused primarily by temperature increases, which shortened the duration of the crop life cycles (particularly the grain filling periods). At some northern sites, yields increased, probably because crop growth is temperature limited at these higher latitudes. Yield decreases were low to moderate. Adaptation strategies were identified that compensated for the negative effects of climate change at some, but not all, sites. These strategies included changing planting dates and shifting to cultivars more adapted to the projected future climate.

While studies have shown that effects on total U.S. agricultural productivity and economy as a whole are likely to be small to moderate, significant regional change is likely. Warmer temperatures may shift much of the wheat-maize-soybean-producing capacity northward, somewhat reducing U.S. production and increasing production in Canada (Rosenzweig et al., 1994). The northern states could become more productive for annual crops such as maize and soybean because of the lengthening of the frost-free period, while the southern states could become less productive for grain crops, due to heat and moisture stress. The south and southeast agricultural regions may undergo especially significant change. Here the yields and production of maize and soybean seem likely to decline, although fruit and vegetable production may be introduced to replace them in part (Rosenzweig et al., 1996).

Across all agricultural regions of the U.S., the demand for irrigation is likely to increase. Higher temperatures and higher potential evaporation will increase peak crop water demand. Changes in farm profitability, especially if declining yields bring higher farm-gate prices, may further encourage the spread of irrigation systems (a trend already underway). However, the availability of water supplies to satisfy the increased demand from the U.S. farm sector may be limited. Moreover, existing irrigation systems may be subjected to climatic conditions for which they were not designed.

Mexico

Projected climate change caused simulated maize yields to diminish dramatically in two main agricultural regions, but the magnitude of the change varied with climate scenario and the initial set of management variables selected for the simulation. The simulated yield reductions were counteracted to some degree by the inclusion of beneficial physiological CO_2 effects. A sensitivity analysis indicated that global warming would be followed by severe declines in crop yields unless irrigation was provided, fertilizer use was increased, or new varieties that are more heat tolerant were developed and adopted (Liverman et al. 1994).

5. SOCIO-ECONOMIC IMPACT OF CLIMATE CHANGE ON DEVELOPING COUNTRIES

The need for action is pressing in order to feed the expanding human population, expected to increase by almost one billion people per decade for the next three decades at least. Much of this increase will occur in developing countries in the low-latitude regions of the world. To meet the associated food demand, crop yields will need to increase, consistently, by over 2% every year through this period.

Most research on agriculture and climate change has focused on potential impacts on regional and global food production, yet few studies have considered how global warming may affect food security. Food security has been defined as "access by all people at all times to enough food for an active, healthy life." (World Bank, 1986). The World Food Summit, convened in 1996 by the Food and Agriculture Organization of the United Nations in Rome, highlighted the basic right of all people to an adequate diet and the need for concerted action among all countries to achieve this goal in a sustainable manner (FAO, 1996).

The overall world production changes mask a disparity in response to climate change between developed and developing countries. The largest negative changes are predicted to take place in developing regions, although the extent of decreased production varies greatly from country to country, depending on the specific nature and degree of the local change in climate. The welfare effects of climate change on individual countries will not only depend upon changes in domestic yields, but also on changes in world prices, and the country's relative strength as an exporter and importer. Cereal-price increases resulting from climate-induced reductions in yield are estimated to range between 24 and 145%. The combination of production declines in developing countries and increases in prices due to climate change would increase the number of people at risk of hunger.

Furthermore, the results show that adaptation strategies do little to reduce these disparate effects. This is due to the fact that developed countries have many more resources to utilize in adaptation strategies than do developing countries. Globally, both minor and major levels of adaptation can help restore world production levels (especially when CO_2 physiological effects are included), compared to climate change scenarios with no adaptation. Low level adaptation largely offsets the negative climate change effects on yields in developed countries, thus improving their comparative advantage in world markets. However, developing countries are predicted to benefit little from this level of adaptation, and may experience a negative change of -9% to -12% in cereal production. More intensive adaptation may effectively eliminate the overall global reduction of cereal yields. Whereas under low adaptation cereal price increases range from 10 to almost 100%, under more intensive adaptation the compounding price responses range from a decline of 5% to an increase of 35%.

Not only do preliminary analyses of direct effects of global warming indicate greater adverse effects in poor countries, but these same countries are less able to achieve the changes required for adapting. Less developed countries also tend to have less developed capital markets, with access for farmers being a pervasive and chronic problem for many. High interest rates are common even where loans for the agricultural sector can be obtained. If the needed adjustments require investment, these factors will slow or eliminate farmers' ability to adapt.

Alternative assumption -lowering of trade barriers, low economic growth, and low population growth- were tested both in the absence and in the presence of climate change. Without climate change, the combination of full trade liberalization and low population growth would have beneficial effects on the world food system, whereas the effects of low economic growth would be detrimental. With climate change, the beneficial effects of full trade liberalization and low population growth would be equal to or even exceed the otherwise adverse effects of climate change. Therefore, there may be much to be gained from altering the conditions of trade and development as a strategy for helping to mitigate potentially negative climate change impacts. In the absence of such measures, cereal production would tend to diminish, particularly in the developing world, while prices and population at risk of hunger would increase due to climate change.

The unequal distributional aspects of climate change are further supported by differences in income level (poor peasants have a higher degree of risk aversion, they are likely to use fewer purchased inputs and to be less able to make large purchases of equipment; the premium put on assuring minimal levels of production of needed food crops may inhibit rapid shifts in farming systems), access to credit and possibility for diversification (monoculture producers in vulnerable areas -tropical developing countries- will be more heavily affected).

Given a presumption of adverse effects in tropical areas, developing countries can expect a slowdown of growth and a decrease in agricultural incomes. Given the large percentage of the labour force engaged in agriculture in low income countries, this effect is likely to increase overall income inequality within countries. Urban-rural disparities would also increase with resulting increases in urban migration and overcrowding.

How, then, may climate change alter the ability of the world's growing population to gain access to food? For subsistence farmers and people who now face a shortage of food, lower yields and yield quality, when and if they occur, may result not only in measurable economic losses but also, indeed, in malnutrition and possibly famine. A compendium of recent work on this topic is found in Downing (1995)

Vulnerability to famine is a complex concept that integrates environmental, social, economic, and political aspects. Groups most vulnerable to climate change in regard to food security may be those who are most exposed to the risk of climate change impacts on crop productivity and changes in commodity prices, with the least capacity to cope with unfavorable changes in agricultural conditions and to access food, and therefore, prone to suffer the severest consequences of famine, malnutrition, and debility.

Groups vulnerable to hunger in the present, and likely to be vulnerable to climate change effects in the future, include rural smallholder farmers, pastoralists, wage laborers, urban poor, refugees, and other destitute groups.

Of these, the most vulnerable to the negative effects of climate change are probably rural subsistence farmers, landless wage earners, and urban poor: they have little food security now and therefore are susceptible to even small changes in agroclimatic circumstances or economic status (Bohle et al., 1994). For households that both raise food and work off the farm, climate change may affect the time for crop planting, but this may conflict with critical off-farm employment.

In the Basic Linked System, the number of people at risk of hunger was defined as those people in developing countries (excluding China) with an income insufficient to either produce or procure their food requirements.

The BLS estimates that with climate change, declines in yields in low-latitude regions are projected to require that net imports of cereals increase under all scenarios tested. Higher grain prices will affect the number of people at risk of hunger. For the climate change scenarios without adaptation, their estimated number increases 1% for each 2-2.5% increase in prices. The number of people at risk of hunger grows by 10-60% in the scenarios tested, resulting in an estimated increase of between 60 million and 350 million people in this condition, by 2060.

With less agricultural production in developing countries and higher prices for foodstuffs on international markets, the estimated number of people at risk of hunger will inevitably increase. The largest increase occurs with a global mean surface temperature rise of 5^0C and with no beneficial physiological effects of CO_2 on crop growth and yield. The smallest change, a decline of 2%, is seen to occur with a 4^0C warming, full CO_2 physiological effects on yields, and high levels of farmer adaptation. As a consequence of climate change and adaptation level 1, the number of people at risk of hunger increases by 40-300 million (6-50%) from the reference scenario of 641 million people.

The study also tested the effects of climate change with alternative assumptions including full trade liberalization, lower economic growth rates, and lower population growth rates. In all these cases, cereal production was seen to diminish, particularly in the developing world, while prices and population at risk from hunger increased due to climate change.

Case studies regarding Zimbabwe, Kenya, Senegal, and Chile have illustrated how climate change can heighten the risk of famine in countries that are already vulnerable (Downing, 1992). Research in Mexico has shown that global warming may present a threat to local and national food security in that country, especially if farmers are unable to adapt to a drier climate and as food imports from other regions become more costly (Liverman and O'Brien, 1991; Appendini and Liverman, 1994). In southern Africa, sensitivity to climate change is multifaceted, especially as affected by potential declines in water resources, loss of important wetland habitats, reduction in biodiversity, impairment of hydroelectric power generation, spread of disease vectors, deterioration of productivity in the rainfed agricultural sector, and attendant declines in food security (Magadza, 1994).

In Zimbabwe, groups currently vulnerable to hunger include unemployed and partially employed workers in urban areas, as well as altogether communal farmers, farm workers, and landless people in rural areas (Christiansen and Stack, 1992; Bohle et al. 1994). Maize is the main staple crop in Zimbabwe, but only 10 to 20% of communal farmers consistently produce a surplus (Downing 1992). Risk of drought is high, and crop failures have been associated with El Niño Southern Oscillation events (Cane et al. 1994). Climate change may lower maize yields in Zimbabwe due to shortening of the favorable growing period and increasing water stress (Muchena, 1994; Muchena and Iglesias, 1995). Simulations with a crop model that tested the effect of a 2% warming for Chisumbanje, a site in the semi arid zone, showed that adequate yields currently expected 70% of the time would occur in fewer than 40% of the years. Furthermore, climate change is likely to cause significant spatial shifts in agricultural capability and land-use zones, with wet zones diminishing and dry zones expanding due primarily to rises in potential evapotranspiration (Downing, 1992).

6. THE KYOTO CONFERENCE

The objective of the Rio climate convention was clearly stated: to stabilize the world's atmosphere so as to prevent dangerous interference with global weather patterns. So far, however, little progress has been made toward that ambitious goal.

Combustion of fossil fuels has continued to grow, releasing ever greater amounts of carbon dioxide, the leading greenhouse gas. Global carbon emissions from fossil fuels reached a record of just over 6 billion tons in 1995. Roughly 1.6 billion tons of additional carbon are emitted from forest clearing each year. Meanwhile, of the 35 industrial countries that committed themselves under the treaty to hold their greenhouse gas emissions to 1990 levels in the year 2000, only about half appear likely to meet that target. In some developing countries emissions are on course to nearly double between 1990 and 2000.

In December 1997, representatives of more than 160 nations assembled in Kyoto, Japan, to sign a historic protocol to the 1992 Framework Convention on Climate Change. The challenge laid down at the Kyoto summit was to spur a steady, gradual descent from this century's precipitous climb up a greenhouse gas mountain.

In the run up to the Kyoto Conference, there were a number of bodies debating a variety of issues. The most positive position came from the Association of Small Island States (AOSIS), which seeked a target of a 20% reduction in CO_2 emissions from industrialised countries by 2005. Ranged against them were the fossil fuel exporting nations such as the Gulf states, Australia and the US. Saudi Arabia and Kuwait requested the integrated development of compensation mechanisms to balance potential lost oil revenue. The US meanwhile, proposed elements such as banking and borrowing of emissions, multiyear emissions budgets and emissions rating. The middle ground was occupied by the EU, with its newly adopted 15% reduction target by 2010 for CO_2, methane and nitrous oxide combined

What has been agreed:

- the industrialized countries are to reduce their collective emissions of six greenhouse gases legally binding by 5.2% (average) until 2012. Developing countries do not have to cut emissions, but will receive additional financial resources and environmental friendly technology;

- the six gases are to be combined in a “basket”, with reductions in individual gases translated into “CO_2 equivalents” that are then added up to produce a single figure.

- calculations will consider ’sources’ and ’sinks’ (e.g. forests);

- specific targets for specific countries were set: the EU, Switzerland, central and eastern European countries will reduce emissions by 8%, Canada, Hungary, Japan and Poland by 6%, Russia, New Zeland and Ukraine are to maintain current levels, whereas Norway (1%), Australia(8%) and Iceland (10%) can emit more gases. The EU may reach its overall target by summing up member states emissions;

- Each country's emissions target must be achieved by the period 2008-2012. It will be calculated as an average over the five years. “Demonstrable progress” must be made by 2005. Cuts in the three most important gases -carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)- will be measured against a base year of 1990 (with exceptions for some countries with economies in transition). Cuts in three long-lived industrial gases -hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) - can be measured against either a 1990 or 1995 baseline;

- international trade with emission titles will be allowed;

- a new financial instrument will be developed to support ’clean technologies’;
- the signing countries may reduce emissions by efforts for a higher energy efficiency, reforms of

energy and traffic policies, protection of forests and other carbon sinks, support of renewables and phasing out of counterproductive guidelines and policies and measures;

- the protocol must be ratified by at least six national governments representing at least 55% of the worldwide emissions in 1990. The protocol was opened for signature for one year starting 16 March 1998. It will enter into force 90 days after it has been ratified. In the meantime, governments will continue to carry out their commitments under the Climate Change Convention. They will also work on many practical issues relating to the Protocol and its future implementation at their regular COP and subsidiary body meetings.

6.1 The EU approach

In 1997, and in the run up to the Kyoto Conference there were a number of bodies debating a variety of issues. The middle ground was occupied by the EU, with its newly adopted 15% reduction target by 2010 for CO_2, methane and nitrous oxide combined.

6.2 The US approach

The US proposed elements such as banking and borrowing of emissions, multiyear emissions budgets and emissions rating.

6.3 Evaluation of the results achieved

At the heart of the issue are the calls for immediate action on limitations and reductions on greenhouse gas emissions. The urgency stems from recognition of the inertia of the climate system and the conclusion by IPCC that only about half, or less, of the global warming due to observed increases in greenhouse gas concentrations has so far occurred. The inertia implies that any measure taken to slow down the warming will become effective only gradually. And, moreover, the inertia of the climate system also implies that once a significant change of climate has occurred, it will not disappear quickly, even if drastic measures were to be taken after the change.

According to a Small Islands report, while the outcome is lower than the 20% target the 35 countries of the Alliance for Small Islands States (AOSIS) had been pushing for, it still is a good result for island countries. Similarly, WWF stated that the result of the Kyoto Treaty -a midpoint compromise between Europe's initial call for a 15% reduction and the US proposal for stabilization- was much stronger than most observers had thought possible.

The WWF president applauded the completion of the new international accord to control greenhouse gas emissions, calling it 'a critical first step in addressing the threat to nature posed by climate change'. WWF also pledged its support for ratification by the US senate:
'The Kyoto climate treaty is truly a historic first step -the first legally binding commitment to control the emissions of heat-trapping gases that threaten wildlife and habitats around the world. It deserves the full support of the conservation community and the American people.'

However, the Kyoto Protocol is still incomplete. Although it was decided to reduce emissions among the developed countries, 'Only the considerable loopholes that have emasculated the actual reduction in emissions is conspicuous' the Head of an environmentalist group, Climate Forum, said. One such loophole is the right to trade in emissions. This system permits countries that have achieved more than their target reduction to sell their extra reduction quota to other countries. If a country purchases emission rights they will be able to clear their target reduction according to the treaty very easily, even if they do not reduce emissions of greenhouse gases domestically.

By targeting industrial emissions, the message coming out of Kyoto is clear: human activities are the root of the climate change crisis. However, the Kyoto accord does not set goals equal to the problem. RAN and other NGOs are calling for an end to new fossil fuel exploration, and the summit paid little attention to the effects on the planet's climate of cutting down old growth trees.

Old growth forests provide the environment with a valuable carbon sink, which counteracts the warming effect by absorbing greenhouse gases -including CO_2, the gas created by fossil fuel emission. Scientists figure that about 50% of the climate change crisis we now face is due to 'land use changes' of the past century -including cutting down old growth forests and converting them into tree farms or agribusiness ventures. Ongoing deforestation accounts for 20% of the problem addressed in Kyoto.

The Framework Convention on Climate Change has the potential to help cultivate a new relationship with forests. Under the Kyoto protocol, nations committed to reducing their greenhouse gas emissions must include in their calculations the changes to their carbon stock resulting from 'afforestation, deforestation, and reforestation'. While it could offer an important incentive for countries to better recognize the value of forests and provide an avenue for poorer nations to receive some international assistance, the protocol has yet to determine how, or whether, tree harvesting and replanting are included within these three activities. This potential loophole could allow a nation to exclude the carbon emitted from harvesting a forest, yet get credit for the carbon absorbed by the subsequent regrowth. If nations do not get credits for maintaining existing forest stocks or debits for harvesting, a potentially powerful disincentive for forest conservation may be created. Signatories to the protocol will have an opportunity to close this loophole when they meet again in late 1998 (Worldwatch paper 140).

The agreement provides only the broadest framework -the targets, timetables, reporting requirements, and trading mechanisms needed to deal with climate change -and leaves to national governments the responsibility for enacting new policies that will enable them to meet the goals. The success of this endeavour will therefore hinge largely on the measures undertaken by individual countries to reduce their emissions of greenhouse gases. Only a diverse portfolio of policies can ultimately reverse the growth of emissions, including fiscal, regulatory, voluntary, and market-based approaches.

The treaty negotiators in Kyoto acknowledged that the Kyoto Protocol represents only a first step toward achieving the goal set by the original climate treaty: to stabilize greenhouse gas concentrations in the atmosphere "at a level that would prevent dangerous interference with the climate system". **Even if the Kyoto Protocol is ratified and nations abide by its terms, neither of which can be taken for granted, its effect will only slow - not halt - the buildup of greenhouse gases. Unlike the Montreal Protocol on Substances That Deplete the Ozone Layer, which will eventually "solve" the problem of ozone depletion if adhered to, the Kyoto Protocol will not "solve" the problem of climate change, but only begin the long process of weaning the world away from heavy reliance on fossil fuels and other sources of greenhouse gases.** Calculations by the IPCC make it clear that emission reductions well beyond any contemplated in the Kyoto treaty will be needed to stabilize atmospheric CO_2 concentrations at even two or three times their preindustrial level of 280 parts per million. For instance, stabilizing CO_2 concentrations at double their pre-industrial level would require eventually reducing global carbon emissions (from all nations) by 60% from 1990 levels.

6.4 Different future scenarios based on the results of the Kyoto Conference

6.4.1 1st scenario: US congress ratification

The White House had made clear that in exchange for US commitments it expected developing countries to enlarge their own participation under the agreement. Congress has expressed similar sentiment. With a view that the Kyoto agreement may not be sufficiently concrete on the role of developing countries, the administration may seek additional assurances before it signs the treaty and forwards it to the Senate ratification.

If ratified, it would tie most developed countries to cutting greenhouse gas emissions early in the next century, in most cases by 8% from 1990 levels. These measures will become effective only gradually.

Some business leaders have expressed concern that cutting greenhouse gases could also cut jobs, but specialists in the environmental services sector denied it. A well designed effort to deal with the climate problem could actually increase economic output.

The challenge for policy makers is to devise and carry out such a strategy -one that simultaneously helps stabilize climate and strengthens economies. In moving forward to implement the Kyoto protocol, there is much to be learned by looking back at government experiences over the last decade in three key areas: reforming fossil fuel prices; boosting energy efficiency standards; supporting the use of renewable energy.

6.4.2 2nd scenario: no ratification of the US congress

Opposition to the treaty is strong among US farm groups. They claim that all of the proposals would spell disaster for American farmers: a significant hike in farm production costs, which translates into a drop in farm income; reduced US farm exports and higher food costs for consumers, especially poorer ones.

If not ratified, the IPCC estimates that a doubling of CO_2 concentrations -likely to occur late next century if we stay on the current path - will increase global temperature by 1-3.5 degrees Celsius. This rate of change, the fastest in the last 10,000 years, poses substantial risks to the natural world and human society in coming decades. While the complexity of the Earth's climate system makes it impossible to know precisely the effects of rapid changes in the composition of the atmosphere, scientists around the world have concluded that flooded cities, diminished food production, and increased storm damage all seem likely -and could well produce catastrophic economic consequences.

7. CONCLUSIONS: Options for Action by the European Parliament

The trend toward rising concentrations of greenhouse gases, if allowed to continue, seems bound to result in significant warming during the coming decades. Even if the Kyoto Protocol is ratified and nations abide by its terms, neither of which can be taken for granted, its effect will only slow - not halt - the build-up of greenhouse gases. Unlike the Montreal Protocol on Substances That Deplete the Ozone Layer, which will eventually "solve" the problem of ozone depletion if adhered to, the Kyoto Protocol will not "solve" the problem of climate change, but only begin the long process of weaning the world away from heavy reliance on fossil fuels and other sources of greenhouse gases. Calculations by the IPCC make it clear that emission reductions well beyond any contemplated in the Kyoto treaty will be needed to stabilize atmospheric CO_2 concentrations at even two or three times their pre-industrial level of 280 parts per million. For instance, stabilizing CO_2 concentrations at double their pre-industrial level would require eventually reducing global carbon emissions (from all nations) by 60% from 1990 levels.

It has been stated that if industrial countries gained confidence that developing countries would join them in the move away from fossil fuels, they might be more ready to embrace stronger emissions limits. However developing countries can only proceed with that transition if industrial countries are actively commercializing the needed technologies.

Institutional innovations could help the world resolve the unprecedented diplomatic complexity posed by the climate problem. They might include an equitable phase-in of stronger developing-country commitments through an accelerated transfer of funds and technology; widespread industry involvement in disseminating information on carbon-free technologies to the developing world's nascent industries; and a heightened role of the EU along with the U.N. and the World Bank in spearheading technological cooperation on climate abatement technologies.

As climate change is predicted to take place over a period of decades to perhaps centuries, society may have some time to study the potential impacts and develop effective mitigation and adaptation actions. The dilemma is that remaining passive while awaiting a complete understanding of climatic processes and absolute proof of global warming may prevent timely and effective action to protect our agroecosystems from serious deterioration. The dilemma is compounded, however, because not only are we faced with the possibility that we may fail to act when we should act but also that we may act unnecessarily or ineffectually. This situation lead some to argue for "no regret" actions, undertaking those strategies that make sense for reasons other than just climate change mitigation or adaptation alone (C. Rosenzweig and D. Hillel, 1988).

A global policy and research effort to speed up reforestation, promote soil conservation, and encourage energy conservation to increase the magnitude of the natural sinks for CO_2, and reduce consumption of fossil fuels, would be "no-regret" approaches. (S.H. Wittwer, 1995).

Many valuable policy lessons have been learned over the past few years that may point the way to solid progress in the post-Kyoto era. Among the policies adopted so far, it is clear that the removal of energy subsidies has had the greatest short-term impact on emissions trends, in some cases contributing to sharp reductions. This, however is largely a one-time effort and, with the possible exception of Australia, Canada, China, Germany and Russia, many countries no longer have sizeable energy subsidies to eliminate. Today's high subsidies for road use offer additional unrealized potential for lowering emissions. Experience shows that energy and emissions taxes can have a significant impact, but so far - with the partial exception of gasoline taxes - few countries have found the political courage to add new significant energy taxes. A further lesson that can be drawn from the policy record to date is the proven effectiveness of energy efficiency standards, although the slow turnover of devices such as automobiles and home appliances means that it will take time for their full impact to be felt. Unfortunately progress in setting new energy efficiency standards over the past five years has been limited. Governments have so far been most aggressive in pushing standards for buildings and appliances, but have been reluctant to adopt auto fuel economy standards in the face of strident industry opposition. Some of the most innovative policies for climate change mitigation involve new incentive mechanisms used to encourage reliance on renewable energy and co-generation. Countries such as Denmark, Germany and India have shown that the right combination of tax incentives and generous purchase prices can spur private industry to invest large sums in these technologies, allowing them to make sizeable contributions to reductions in carbon emissions in coming decades.

As far as forests are concerned, it is now apparent that new sources of financing will need to be found if forests are to contribute to balancing the carbon budget. A growing number of developing countries have started to attract private investment for carbon sequestration, while a few industrial countries are beginning to draw up public support for increasing forest area. One promising innovation that has emerged but is not widely employed is the partial use of carbon tax revenue to support forestry projects. Overall, carbon storage remains one of the most cost-effective yet least exploited means of slowing climate change.

Preventive methods of global climate change concerning agriculture are intrinsically linked to methods promoting sustainable cultivation and sustainable forms of agriculture. From the sustainability point of view the agricultural sector has shown some disconcerting developments over the last decades. Although there have been great improvements in food security, the negative impacts of the “green revolution” on the environment as well as on employment, animal welfare and third world markets are striking. In the European Union, these developments are enabled, if not actively stimulated by current agricultural policy, in particular the European Union Common Agricultural Policy (CAP).

There is currently the opportunity to make key areas of European Union policy more sustainable. In March 1998 the European Commission adopted legislative proposals for reform of the CAP based on a package of measures entitled Agenda 2000, a key strategy document in which the Commission sets out its view on how the EU should develop its common policies beyond the year 2000. Ongoing discussions on the proposals for reform of the CAP are scheduled to continue up to the first half of 1999.

The policy document Agenda 2000 reflects the rapidly changing context for European agricultural policy, emphasising a welcome shift towards a more quality-oriented agriculture policy and towards consideration of the rural economy as a whole, with emphasis on employment. Although the general direction for change is set by Agenda 2000 and global developments, providing the opportunity for reaching the objectives for sustainable agriculture, many unresolved issues remain to be considered further as reform of the CAP gathers pace. The new CAP will need to be driven by much stronger environmental imperatives. Sustainability will need to be pursued through integration across and within all economic sectors (such as transport, energy and agriculture) and agricultural product markets. Consistency between all policy areas will minimise potential conflicts that may arise from integration.

Five core conclusions can be reached, regarding the policies that will need to be pursued if the shift to sustainable agriculture is to be achieved:

Market conditions will need to be created that enable farmers to promote sustainability while preserving their competitiveness in a global market. Globalisation and trade liberalisation, by requiring the need to preserve product competitiveness, can be in direct conflict with sustainable development objectives. Solving these and other potential conflicts will involve the European Union playing a leading role within the World Trade Organisation. The preamble to the World Trade organisation recognises the need to protect the environment and to promote sustainable development. The Uruguay Round Ministerial Decision on Trade and Environment ensures that linkages between trade policies, environmental policies and sustainable development will be taken up as a priority in the World Trade Organisation.

Local policy implementation will need to be promoted and diversity of nature and products will need to be preserved across the entire agriculture and food chain in such a way that high standards of environmental protection are achieved. A balance is required to be achieved between clear strategic objectives set at EU level and implementation devolved from Member States to local communities in order to develop locally appropriate and tailored solutions. Local products grown organically must not be prevented market access due to the fact that their size, form or colour does not meet EU technical standards.

There is a need to recognise and evaluate those environmental and social impacts which are not reflected in the price of goods and services. Policy should take full account of these impacts at the policy, business and individual levels in order to ensure accountability by all stakeholders. Hidden subsidies, for example, should be made transparent and community funds should not support unsustainable practices. Eventually environmental and social impacts should be reflected in the price of goods and services, on the basis of the polluter pays principle, which would in addition allow organically grown produce a more competitive position in the market.

More sophisticated linkages within different environmental policy instruments need to be promoted to achieve a consistent approach to sustainability. One example is the need to ensure that measures for sustainable agriculture support and compensate as well as being supported and compensated by transport and energy policies. Further steps will need to be taken to develop an integrated decision-making system within Community institutions and committees.

The result should be a policy framework that promotes a system of agriculture which produces wholesome food made available to consumers in a sustainable manner, enhancing and sustaining rural communities, the environment and quality of life. For farming itself this would require the avoidance of methods of increasing productivity that bring about environmental and social degradation. The European Commission's proposed reform of the CAP contains some promising elements, including a shift from price support to direct payments, the possibility for attaching environmental and landscape conditions to payments ("cross compliance") and the comprehensive approach to rural development. However the most positive measures are voluntary for Member States. A small number of major adaptations could allow a move towards sustainable agriculture:

Cross-compliance should be made compulsory for all Member States in a form which ensures environmental progress. Ground rules and guidelines for cross compliance and for codes of good practice should be set at EU level, although setting nature and landscape conditions is best carried out on a national level.

The role of rural development should be enlarged and the approach made truly sustainable. To this end the budget for rural development should be substantially increased (at the possible expense of export subsidies) and greened in order to allow Member States to use this instrument more intensively. In addition to the agri-environment measures being compulsory (which is already the case), there should also be a clear earmarking of a substantial amount in the budget for such measures

The entire CAP reform should be subject to a comprehensive strategic environmental impact assessment (SEA). Such an SEA should cover the projected impact on the environment (including climate effect, biodiversity, landscape and animal welfare) of the full package of CAP measures as proposed. It should be mandatory that, based on the outcome of the SEA, further adjustments in the CAP are made in the near future.

Methods of sustainable agricultural development directly related to climatic effects, to be incorporated into European and global policy include methods for minimizing emissions of carbon dioxide, methane and nitrous oxides:

The goal for CO_2 reductions from the agricultural sector should be to make sure that the land is used as efficiently as possible, thereby maximizing the preservation of non-cultivated areas such as forests. This goal is particularly important in light of predictions which suggest that agricultural land could increase by 60% by 2025. Further, on cultivated lands, practices should aim to limit soil erosion through minimization of tillage practices. Finally, the use of more energy efficient farm implements should be promoted.

Realistic options for the reduction of methane emissions include the improvement of ruminant nutrition levels through feed additives. Waste management practices should strive to ensure aerobic conditions at all times to minimize potential CH_4 releases. Such practices include minimizing the lagooning of wastes (unless a methane collection system is present), prompt application of wastes as fertiliser on fields and the use of wastes as a fuel source. Research needs to continue on minimizing methane emissions from flooded rice paddies, possibly through the selection and development of cultivars and changes in the nutrient and water management practices.

Reducing nitrous oxide emissions from the agricultural sector requires improved nitrogen management, with the goal of leaving as little residual nitrogen as possible in the soil during non-cropped periods of the year. Practices for accomplishing this goal can be summarized as paying closer attention to the use and management of fertilizer techniques.

The Maastricht Treaty on European Union, which entered into force in November 1993 embodies the principle of sustainability and reinforced environmental policy by clearly stating the obligation of integrating environmental requirements in all EU policies.

Agriculture is one of the selected target sectors of the *Fifth Environmental Action Programme* adapted by the Commission in 1992. The programme lays down the fundamental objectives of maintaining the basic natural processes indispensable for a sustainable agricultural sector, through the conservation of water, soil and genetic resources. The Programme also sets out specific objectives namely, to reduce chemical inputs, to achieve a balance between nutrient inputs and the absorptive capacity of the soil and plants, to promote rural environmental management practices, to conserve biodiversity and natural habitats and to minimise natural risks. Climate change is included in the principal themes and targets of the Programme and is recognised as a particularly important problem due to the close link with various Community policies, including agriculture.

The EU is committed to support sustainable agriculture at the international level. To this aim the European Commission could contribute actively through its current participation in the works of the UN Commission on Sustainable Development which monitors the implementation of Agenda 21.

Agricultural systems are adjustable, being subject to our control -but only by adapting management practices to altered circumstances. If there is a change in climate, agriculture will have to adapt in order to minimize the negative effects of the climatic change. Government policies may tend to thwart rapid adjustment to environmental changes. In such cases removal of governmental intervention often promotes greater flexibility and thus reduces vulnerability to climate stress. Internationally, lowering barriers to trade in agricultural commodities, as has been pursued under the General Agreement on Tariffs and Trade (GATT) should help the world food system adjust to climate changes more rapidly.

At the policy level, obstacles to change are created by supporting prices of crops that are not well suited to a changing climate, by providing disaster payments when crops fail, and by restricting competition through import quotas. Programmes could be modified to promote flexibility in the choice of crops and to improve the basis for crop disaster payments.

The task of assessing adaptation policies includes analyzing the effectiveness or shortcomings of current policies in coping with climate change, calculating the costs and benefits of alternative policies designed to mitigate climate change impacts, and identifying policies with highest priority for immediate implementation. Policy makers should be invited to participate in this assessment.

High priority in adaptation policy should be placed on avoiding irreversible or catastrophic impacts (such as eradication of species), preventing climatic extremes from damaging long- term projects and halting trends that are likely to thwart future adaptation to climate change.

With accurate forecasts, purposeful adjustments can be incorporated in sectoral activities and planned responses. This class of responses would involve considerable investment for which there would be little benefit in the immediate future, and little benefit if climate change does not occur. The timing of such adjustments is critical, as is the need for reliable regional forecasts of climate change. Examples are higher sea walls and larger reservoirs to cope with sea level rise and the risk of droughts and floods. Both have negative environmental consequences, so they would only be justified if the impacts of climate change are likely to be serious.

In view of the present uncertainties over the pace and magnitude of climate change, the most promising and most cost-effective policy options of agricultural adaptation are ones for which benefits accrue even if no climate change takes place. Small changes can be accommodated in the normal course of development. These would entail relatively little cost and would be incorporated into existing planning mechanisms without major institutional development. Such policy options include the following:

Liberalization of trade. Removing barriers to international trade in agricultural commodities, as under the GATT (now established within the WTO under the Uruguay Round), should help the world food system to adjust to climate changes more efficiently and rapidly.

Flexibility of commodity support programmes. Commodity support programs often discourage farmers from changing cropping systems, and this may hinder adaptation to climate change. Efforts to stabilize food supplies and maintain farm incomes should avoid disincentives for farmers to switch and rotate crops. Such a policy will induce greater efficiency in farming practices and promote flexibility in the face of future climate change.

Dissemination of conservation management practices. Conservation tillage, furrow diking, terracing, contouring, and planting windbreaks protect fields from water and wind erosion, and retain soil moisture by reducing evaporation and increasing infiltration. Use of biologically intensive management practices such as green manures, cover crops, intercropping, agroforestry, and crop rotation as well as the maintenance of ground cover and the introduction of shelter belts protect fields from soil erosion. Improving rainfed (dryland) farming can reduce dependence on irrigation, save water, and allow greater resiliency in adapting to climate change.

Agricultural drought management. Drought is an intrinsic feature of the climate prevalent in many agricultural regions . Mistakenly, it is commonly seen as a natural disaster rather as an inevitable occurrence (though of irregular frequency, duration and intensity). Drought management can be improved by providing information about climatic conditions and patterns, sound preparatory practices and options for the eventuality of drought, and appropriate insurance programmes. Farm disaster relief and other government subsidies, however, may distort markets and encourage the continuance and even expansion of farming marginal lands.

Promoting efficiency of irrigation and water use. Presently wasteful surface irrigation systems may be converted to more efficient sprinkle, drip and micro-spray techniques. Drainage water and wastewater may be reused for irrigation. Evaporation and seepage losses can be reduced by encouraging use of night time irrigation, lining of canals, closed conduits, delivery of water in measured quantities and charging for water in proportion to the volume used. Finally, and perhaps most important, water conservation should be promoted by means of public education and consciousness raising.

Protection of permanently flooded areas. Treating the symptoms, such as constructing flood banks to control the course of the river, comprise part of the flood control measures. However, the best solutions tackle the causes as well. Such measures consist of planting new trees in mountain areas; redistributing land so that people are not forced to live in flood areas; controlling climate change.

Improved short term climate prediction. Linking agricultural management to seasonal climate predictions (currently largely based on the El NiZo Southern Oscillation Phenomenon), where such predictions can be made with reliability, can allow management to adapt incrementally to climate change. Management/climate predictor links are an important and growing part of agricultural extension in both developed and developing countries.

Maintenance of seed banks. Collections of seeds are maintained in germplasm banks around the world. These genetic resources must be maintained in order to allow future screening for sources of resistance to changing diseases and insects, as well as tolerances to heat and water stress and better compatibility with new agricultural technologies.

New crop varieties and species. Selective breeding objectives should include heat tolerant and low water-use crops, as well as crops with high value per unit volume of water used. Salt-tolerant crops should be introduced in regions with brackish water supplies or vulnerable to soil salinization. More tolerant crops may enable farmers to diversify and to produce profitably even under adverse conditions.

Different crop varieties or species. If climate change affects the length of the growing season, then farmers should be encouraged to use the adaptation strategy of switching to longer growing, higher yielding cultivars. For most major crops, varieties exist with a wide range of maturation and climatic tolerances.

Investment in agricultural research and infrastructure. Combined biophysical and economic analysis suggests that, in general, agricultural adaptation and market adjustments can moderate the negative impacts of climate change. However, adaptation cannot be taken for granted: improvements in agriculture have always depended on the investments made in agricultural research and infrastructure. Research can identify the specific ways that farmers now adapt to present variations in climate, whether by applying more fertilizer, more mechanization, or more labor. Information of this nature is needed to. Success in adapting to possible climate change will depend on a better definition of what changes will occur where, and on prudent investments, made in a timely fashion. It is noted that the working groups at the Expert Consultation at FAO in 1993 (F. Bazzaz, 1996) identified several research areas which would reduce uncertainty, improve knowledge, increase preparedness in the face of climate change and provide better grounds for policies related to climate change. For example, firm quantitative assessment was indicated as needed of site-specific crop responses as a function of time and growth stage, in particular for perennial crops and crops of greatest importance to food production.

In Europe, climate adaptation policies will need to be combined with or added to existing EU agricultural policies and in particular the EU Common Agricultural Policy, in view of the European Commission's current proposed reform of the CAP as discussed above. The conservation of water, soil and genetic resources are included in the fundamental objectives of the *Fifth Environmental Action Programme* in relation to the agricultural sector. Agricultural research leading to an assessment of potentialities for coping with the threat of a more severe climate in the future should be incorporated into the agricultural and other relevant research programmes implementing the European Community *Fifth Framework Research Programme* (1998-2002). An assessment of the costs and benefits of prevention policies versus alternative adaptation policies regarding the effect of prospective climate change on agricultural production should also be a subject for further research.

The aim of adaptation is to avoid crises. However, if present strategies to handle climatic hazards are insufficient, further disaster preparedness is warranted and may be justified in part for as a means to reduce the risk of large-scale impacts from climate change. A climate change catastrophe scenario would be the collapse of major regional ecosystems, such as fishing grounds, coastal settlements, and semi-arid agriculture. It is likely that planned resilience and purposeful adaptation would be less costly than coping with such large scale effects. In any case, coping with crises often fails to mitigate future disasters and has a high opportunity cost. (T.E. Downing 1998).

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ANNEX 1

Tables & Figures

Table 1.1: The common greenhouse gases, their relative direct sources (percentages of total anthropogenic emissions in 1990) their contribution to global warming and mean atmospheric lifetimes of greenhouse gases with their global warming potentials (GWPs) relative to carbon dioxide. *(Leggett, 1990, p.17; EEA, 1995, p.515; EEA, 1995, p.514)*

Gas*	Principal Sources (percentages of total anthropogenic emissions in 1990)	Contribution to Global Warming (%)	Lifetime (years)	GWP
Carbon Dioxide (CO_2)	Fossil fuel burning (80%) Deforestation (18%) Other (3%)	55	50-200	1
Chlorophluor carbons (CFCs) and related gases (HFCs and HCFCs)	Various industrial uses (100%): refrigerants foam blowing solvents	24	Ranging from 1.7 (HCFC-123) to 550 (CFC-115)	Ranging from 310 (HCFC-123) to 6000 (CFC-114)
Methane (CH_4)	Rice paddies (17%) Enteric fermentation / Animal waste (31%) Energy (26%) Landfills/ Domestic waste (18%) Biomass burning (8%)	15	10.5	63
Nitrous oxide (N_2O)	Biomass burning (11%) Fertiliser use (48%) Deforestation (17%) Energy (9%) Other Industry (15%)	6	132.0	270

* The contribution from tropospheric ozone is also significant, but is very difficult to quantify. Ozone forms in the tropospheric zone as a result of chemical interactions between uncombusted hydrocarbons and nitrogen oxides, produced by fossil -fuel burning in the presence of sunlight.

Table 4.1 Regional crop yield for 2 x CO_2 GCM equilibrium climate *(Reilly et al., 1996)*

Region	Crop	Yield Impact (%)	Countries studied & Comments
Latin America	Maize	-61... to increase	Argentina, Brazil, Chile, Mexico, Range in across GCM scenarios with or without CO_2 effect.
	Wheat	-50 to -5	Argentina, Uruguay, Brazil, Range in across GCM scenarios with or without CO_2 effect.
	Soybean	-10 to + 40	Brazil, Range in across GCM scenarios with or without CO_2 effect.
Former Soviet Union	Wheat grain	-19 to +41 -14 to +13	Range in across GCM scenarios with or without CO_2 effect.
Europe	Maize	-30 ... to increase	France, Spain, N. Europe. With adaptation, CO_2 effect. Longer growing season: irrigation efficiency lost, northward shift.
	Wheat	Increase or Decrease	France, U.K., N. Europe. With adaptation, CO_2 effect. Longer growing season: northward shift, increased pest damage; lower risk of crop failure.
	Vegetables	Increase	*as above*
North America	Maize	-55 to +62	USA and Canada. Range in across GCM scenarios and cities with or without CO_2 effect.
	Wheat	-100 to +234	
	Soybean	-96 to +58	USA. Less severe or increase in yield CO_2 effect and adaptation considered.
Africa	Maize	-65 to +6	Egypt, Kenya, South Africa, Zimbabwe. With CO_2 effect, range across sites and climate scenarios.
	Millet	-79 to -63	Senegal. Carrying capacity fell 11-38%
	Biomass	decrease	South Africa: agrozone shifts.
South Asia	Rice	-22 to +28	Bangladesh, India, Philippines, Thailand, Indonesia, Malaysia, Myanmar. Range over GCM scenarios and cities, with CO_2 effect. Some studies also consider adaptation.
	Maize	-65 to -10	
	Wheat	-61 to +67	
Mainland China Taiwan	Rice	-78 to +28	Includes rain-fed and irrigated rice. Positive effects in NE and NW China. Negative effect in most of the rest of the country. Genetic variation provides scope for adaptation.
Asia (other) Pacific Rim	Rice	-45 to +30	Japan and South Korea. Range across GCM scenarios. Generally positive in Northern Japan, negative in Southern Japan.
	Pasture	-1 to +35	Australia, New Zealand.
	Wheat	-41 to +65	Australia, Japan. Wide Variation, depends on cultivar

Table 4.2 : Summary of modelled crop yield responses to climate change scenarios *(European Commission EUR17470 EN)*

Geographical	[2]UKTR scenarios		[3]GFDL scenarios		Crop	Mean yield impact (%)		[4]Other
scope	[5]ÄÔ (ºC)	[4]ÄÑ (%)	ÄÔ (ºC)	ÄÑ (%)		UKTR	GFDL	effects
[6]*Transient climate change scenarios for 2023:*								
Jokioinen, Finland	+2,0	+11,1	+0,3	-0,8	Cauliflower	+3,0	+2,7	Q-
					Broccoli	+1,7	-0,7	V+
Oxford, U.K.	+1,4	-1,2	+0,5	+8,9	Cauliflower	+4,8	+0,2	Q-
					Broccoli	+2,0	-0,3	V+
					Onion	+11,5	+15,5	V-
Rothamsted, U.K.	+1,4	-1,2	+0,5	+8,9	Wheat	+7,0	+4,6	
Munich, Germany	+1,7	+4,7	+0,6	+5,7	Cauliflower	+2,7	+0,5	Q-
					Broccoli	+1,4	+0,3	
					Onion	+8,9	+7,7	V+
Bologna, Italy	+2,0	-3,6	+0,9	+7,7	Grapevine	+2,5	+13,4	V+
Seville, Spain	+1,9	-13,9	+0,8	+2,7	Wheat	+0,9	+4,8	
Europe	+1,5	+1,1	+0,8	+2,4	Onion	+5,8	+8,1	
					Wheat	+12,7	+12,2	
					Sunflower	-21,4	+16,4	
[7]*Transient climate change scenarios for 2064:*								
Jokioinen, Finland	+3,5	+20,5	+2,7	+7,6	Cauliflower	+3,9	+6,6	Q-
					Broccoli	+1,3	+2,7	V-
Oxford, U.K.	+2,1	+2,9	+1,8	+2,2	Cauliflower	+7,3	+6,4	Q-
					Broccoli	+5,1	+3,1	V+
					Onion	+22,7	+31,9	V-
Rothamsted, U.K.	+2,1	+2,9	+1,8	+2,2	Wheat	+19,9	+28,3	
Munich, Germany	+3,0	+7,8	+2,7	-0,1	Cauliflower	+5,0	+1,8	Q-
					Broccoli	+4,1	1,7	V+
					Onion	+12,8	+11,5	V+
Bologna, Italy	+3,5	-12,2	+2,4	+2,4	Grapevine	-26,0	-1,0	V+
Seville, Spain	+3,6	-42,7	+3,0	-20,0	Maize	-10,3	-5,0	V+
					Wheat	+17,0	+16,8	
[8]Spain	+2,1	-11,4	+2,7	-16,0	Maize	-11,2	-7,0	
					Wheat	+38,8	+18,0	
[7]Europe	+2,7	+2,6	+2,4	+2,1	Onion	+14,5	+13,5	
					Wheat	+27,4	+27,6	
					Sunflower	-7,5	-8,0	

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[2] U.K. Met. Office transient GCM experiment.

[3] Geophysical Fluid Dynamics Laboratory transient GCM experiment.

[4] Q = yield quality, V = inter-annual yield variability, + = increase, - = decrease.

[5] ÄÔ = mean annual temperature change, ÄÑ = mean annual precipitation change.

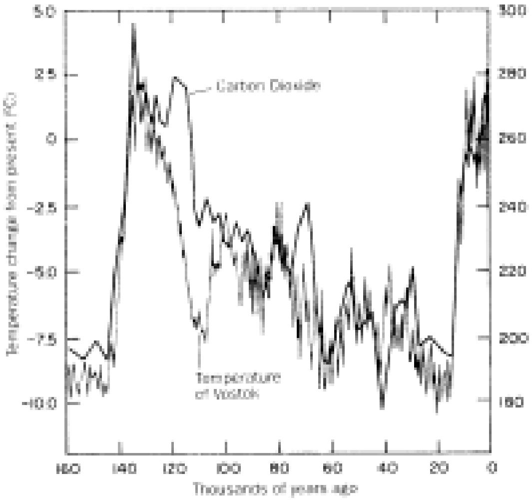
[6] Climate change scenarios constructed from UKTR model for the decade 31-40 and the GFDL model for the decade 25-34. A CO_2 concentration, consistent with the IS92a emissions scenario, of 454 ppmv was assumed.

[7] Climate change scenarios constructed from UKTR model for the decade 66-75 and the GFDL model for the decade 55-64. A CO_2 concentration, consistent with the IS92a emissions scenario, of 617 ppmv was assumed.

[8] Figures are regional averages.

Table 4.3 Categories of regions vulnerable to climate change *(Schmandt and Clarkson, 1992)*

Category	Description	Examples
Coastal regions	Vulnerable to sea-level rise. High -risk regions include low-lying and densely populated areas. May also be affected by land subsidence.	U.S. and Mexican Gulf coast, Netherlands, Bangladesh, Guyana, Baltic sea, Mediterranean sea, Caribbean sea.
River deltas	Threatened by sea-level rise, salty water intrusion, reduced fresh water stream-flow, increased subsidence.	Ganges/Brahmaputra, Nile, Mississippi.
Ocean islands	Vulnerable to sea-level rise. Generally small islands with low elevation.	Maldives, Indonesia and some Pacific islands.
Major food-producing regions	Under current climatic conditions these regions are well-suited to food production. May be vulnerable to more frequent and severe droughts, changes in monsoon patterns or timing of snow-melting, desertification or other climatic stresses.	U.S. Midwest, Ukraine, Argentina, Australia, India, China.
Marginal agricultural regions	Stressed agricultural systems are highly vulnerable to climatic variations. Typical practices include subsidence agriculture and livestock raising.	Sub-Saharan Africa, Northern Mexico, Middle East, Northwest Brazil, Australia, China.
Water-stressed regions	Regions of periodic water shortage or where demand for water is increasing and threatening to exceed the available supplies.	California, Texas, Mexico, China, Middle East.


5.0
2.5
0
-2.5
-5.0
-7.5
-10.0
300
280
260
240
220
200
180
Carbon Dioxide
Temperature at Vostok
Temperature change from present (°C)
160
140
120
100
80
60
40
20
0
Thousands of years ago

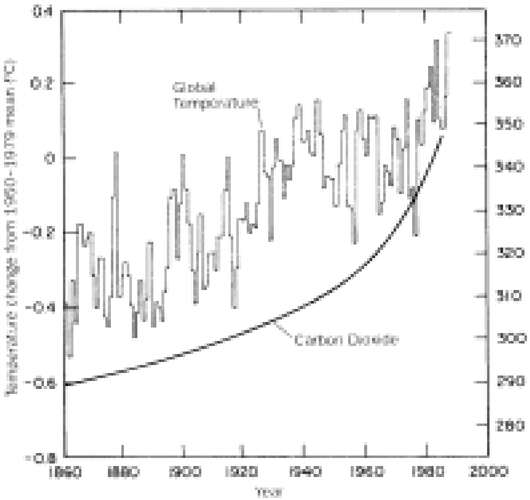

0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
370
360
350
340
330
320
310
300
290
280
Global Temperature
Carbon Dioxide
Temperature change from 1950-1979 mean (°C)
1860
1880
1900
1920
1940
1960
1980
2000
Year

Figure 1.2

ANNEX 2

Main Community texts concerning agriculture and environment

Regulations

Council Regulation (EEC) No 797/85 of 12 March 1985 on improving the efficiency of agricultural structures. OJ L 93 of 30.3.1985.

Council Regulation (EEC) No 1760/87 of 15 June 1987 amending Regulations (EEC) No 797/85, (EEC) No 270/79, (EEC) No 1360/78 and (EEC) No 355/77 as regards agricultural structures, the adjustment of agriculture to the new market situation and the preservation of the countryside. OJ L 167 of 26.6.1987.

Council Regulation (EEC) No 4256/88 of 19 December 1988, laying down provisions for implementing Regulation (EEC) No 2052/88 as regards the EAGGF Guidance Section. OJ L 374 of 31.12.1988.

Council Regulation (EEC) No 3013/89 of 25 September 1989 on the common organization of the market in sheepmeat and goatmeat. OJ L 289 of 7.10.1989.

Council Regulation (EEC) No 866/90 of 29 March 1990 on improvement of conditions for marketing and processing agricultural products.OJ L 91 of 6.4.1990.

Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs. OJ L 198 of 22.7.1991.

Council Regulation (EEC) No 2328/91 of 15 July 1991 on improving the efficiency of agricultural structures. OJ L 218 of 6.8.1991.

Council Regulation (EEC) No 2078/92 of 30 June 1992 on agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside. OJ L 215 of 30.7.1992.

Council Regulation (EEC) No 2080/92 of 30 June 1992 instituting a Community scheme for forestry measure in agriculture. OJ L 215 of 30.7.1992.

Council Regulation (EEC) No 2081/92 of 14 July 1992 on the protection of geographical indications and designations of origin for agricultural products and foodstuffs. OJ L 208 of 24.7.1992.

Council Regulation (EEC) No 2081/93 of 20 July 1993 amending Regulation (EEC) No 2052/88 on the tasks of the Structural Funds and their effectiveness and on coordination of their activities between themselves and with the operations of the European Investment Bank and the other existing financial instruments. OJ L 193 of 31.7.1993.

Council Regulation (EEC) No 2085/93 of 20 July 1993 amending Regulation (EEC) 4256/88 laying down provisions for implementing Regulation (EEC) No 2052/88 as regards the European Agricultural Guidance and Guarantee Fund (EAGGF) Guidance Section. OJ L 193 of 31.7.1993.

Council Regulation (EC) No 3611/93 of 22 December 1993 amending Regulation (EEC) No 805/68 on the common organization of the market in beef and veal. OJ L 328 of 29.12.1993.

Council Regulation (EC) No 3669/93 of 22 December 1993 amending Regulations (EEC) No 2328/91, (EEC) No 866/90, (EEC) No 1360/78, (EEC) No 1035/72 and (EEC) No 449/69 with a view to expediting the adjustment of production, processing and marketing structures as part of the reform of the common

agricultural policy. OJ L 338 of 31.12.1993.

Commission Regulation (EC) No 2515/94 of 9 september 1994 amending Regulation (EEC) No 1848/93 laying down detailed rules for the application of Council Regulation (EEC) No 2082/92 on certificates of specific character for agricultural products and foodstuffs. OJ L 275 of 26.10.1994.

Council Regulation (EC) No 2843/94 of 21 November 1994 amending Regulations (EEC) No 2328/91 and (EEC) No 866/90 with a view to expediting the adjustment of production, processing and marketing structures as part of the reform of the common agricultural policy. OJ L 302 of 25.11.1994.

Commission Regulation (EC) No 746/96 of 24 April 1996 on implementation of Council Regulation (EEC) No 2078/92. OJ L 102 of 25.4.1996.

Council Regulation (EC) No 1404/96 of 14 July 1996 modifying Regulation 1973/92 instituting a financial instrument for the environment *(Life)*. OJ L 181 of 20.7.1996.

Directives

Council Directive 74/63/EEC of 17 December 1973 on the fixing of maximum permitted levels for undesirable substances and products in feedingstuffs. OJ L 38 of 11.2.1974.

Council Directive 75/268/EEC on less-favoured areas. OJ L 128 of 19.5.1975.

Council Directive 76/895/EEC of 23 November 1976 relating to the fixing of maximum levels for pesticide residues in and on fruit and vegetables. OJ L 340 of 9.12.1976.

Council Directive 79/117/EEC of 21 December 1978 prohibiting the placing on the market and use of plant protection products containing certain active substances. OJ L 33 of 8.2.1979.

Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds. OJ L 103 of 25.4.1979.

Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances. OJ L 20 of 26.1.1980.

Council Directive 80/778/EEC of 15 July 1980 relating to the quality of water intended for human consumption. OJ L 229 of 30.8.1980.

Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment. OJ L 175 of 5.7.1985.

Council Directive 86/363/EEC of 24 July 1986 on the fixing of maximum levels for pesticide residues in and on foodstuffs of animal origin. OJ L 221 of 7.8.1986.

Council Directive 90/642/EEC of 27 November 1990 on the fixing of maximum levels for pesticide residues in and on certain products of plant origin, including fruit and vegetables. OJ L 350 of 14.12.1990.

Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market. OJ L 230 of 19.8.1991.

Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. OJ L 375 of 31.12.1991.

Council Directive 92/44/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJ L 206 of 22.7.1992

Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. OJ L 257 10.10.1996.

Documents COM

COM(93) 47 final of 14.5.1993. Communication from the Commision to the Council and Parliament and the Economic and Social Committee : green paper on remedying environmental damage.

COM(93) 575 of 16.3.1994. Proposal for a Council Directive amending Directive 85/337/EEC.

COM(94) 117 final of 11.5.1994. Proposal for a Council Regulation (EC) on reform of the common organisation of the market in wine.

COM(95) 511 final of 31.10.1995. Communication from the Commission to the Council and the European Parliament on the integrated management of coastal zones.

COM(95) 509 final of 22.11.1995. Communication on cohesion policy and the environment.

COM(96) 59 final of 21.2.1996. Communication from the Commission to the Council and the European Parliament. European Community Water Policy.

COM(96) 366 final of 26.7.1996. Proposal for a Council Regulation (EC) supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs to include livestock production.