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**A Global Perspective on Climate Change Impacts on Developing-
Country Agriculture:
Towards a Synthesis and Research Agenda for the Challenge Program
on Water and Food**

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Introduction

While extensive studies have been done on the likely effects of Global Climate Change on US agriculture (Mendelsohn et al., 1999; Adams et al., 1988, 1990, 1999; Rosenzweig and Hillel, 1998), a relatively small proportion of the Climate Change literature has looked at the likely impacts on agriculture in developing countries. Given the relatively abundant data that is available on agricultural producers within the United States and the funding provided by U.S. based sources, like the National Science Foundation, the preponderance of detailed studies that examine the impacts of climate change in the United States is not surprising. Many of the theoretical models and analytical methods applied to the study of climate change in US agriculture, such as hedonic pricing analysis and duality-based theoretical modeling (Mendelsohn et al., 1994), are better suited to a context in which well-functioning markets can be expected to convey the necessary information on underlying producer behavior and preferences through the price data that is observed. In developing countries, however, output and factor markets often function poorly or can be missing altogether, which makes the application of these methods difficult or impracticable.

Several authors acknowledge the acute vulnerability of the poorest households to Global Climate Change, give their heavy dependence on rainfed agriculture and their low ability to buffer shocks to their incomes with assets or market instruments (Mendelsohn and Dinar, 1999; Kurukulasuriya and Rosenthal, 2003). The reliance of rural households on agriculture is a well-known fact for developing countries in Asia, Africa, and Latin America, and the vulnerability of these agricultural producers to shocks in the physical or

economic environment is particularly acute amongst the poorest households, given their small resource endowments (Mendelsohn, 2000). While coping mechanisms such as informal risk-sharing arrangements, migration and the sale of assets have been observed to help smooth household-specific, idiosyncratic shocks, there are no real mechanisms for dealing with aggregate shocks that are correlated across space, such as extreme weather events, and that affect large numbers of poor households within a region (McCarthy, 2004).

Many of the studies looking at the future of global water resources and its effects on agriculture have not taken the impacts of Global Climate Change fully into account. Several studies have taken a long-term view to the future of water resources and the implications of observed trends in groundwater and surface water availability on agricultural yields and production in various regions of the world (Rosegrant et al., 2002; Raskin et al., 1995, 1997). Many of these studies, however, have not taken into account the joint effect of changing precipitation patterns, temperatures and atmospheric conditions – such as carbon-dioxide content – on agricultural yields, as are projected under various Climate Change scenarios (Reilly et al., 2002). By only looking at the future trend of one environmental factor, such as water availability, one cannot obtain a clear and complete picture of the likely impacts that are likely to be experienced by agricultural producers in the decades ahead.

Therefore, it is imperative to look more closely at Global Climate Change within the specific context of developing countries in order to fully understand the likely global trends of poverty and welfare in the future. Given that the rural poor are particularly vulnerable to changes in the natural environment and are limited in their ability to buffer

shocks to their income, the policies aimed at reducing the welfare impact of Global Climate Change within developing countries will have to be targeted specifically to their needs and to the constraints that they face. The challenges faced by female-headed, rural households are even more acute and would warrant special policy and research attention (Lambrou and Lamb, 2004).

By clearly targeting developing country constraints and conditions, a clear agenda of research can be identified for the Challenge Program on Water and Food, so as to direct its current research on poverty and agriculture in developing countries towards addressing the pressing issues that are likely to arise in the coming decades. The research methods for understanding poverty, agricultural production, and natural resource sustainability, that exist in the literature can be combined with existing methods for climate and spatial analysis and new policy modeling at the global and regional levels to create a coordinated and integrated research program that can fully examine the global dimensions of climate change impacts on agriculture and the resource environment that it depends on.

Background and Literature

The economic literature on Global Climate Change has revolved mainly around two themes – namely, the mitigation measures that can be taken to reduce the emission of greenhouse gases that lead to global warming, and the adaptation measures that individual economic agents can take to reduce the harmful effects of climate change. The

distinction between these two actions – mitigation and adaptation – can be most clearly drawn by thinking of mitigation as the actions that address the causes of global warming and climate change, while adaptation is comprised of the actions that are taken in response to climate change, so as to reduce the impact of its effects or to reduce one's own exposure to them.

Yan (2004) describes mitigation strategies as measures that are taken to reduce the emission of carbon or carbon by-products at the “source”, or to sequester carbon before it is emitted, by the use of “sinks”. These measures, which include the adoption of ‘cleaner’ fuels or improved carbon-reduction technologies at the emission sources, have been addressed primarily within the environmental economics and management literature, and treated as a pollution control problem, from a policy perspective. Among the strategies for sequestration of carbon in ‘sinks’ are the adoption of low-tillage farming practices and the improved management of wetlands and forested areas. Even though much of the production of change-causing greenhouse gas emissions emanate from industrialized countries, there are mitigation strategies that could be undertaken within developing countries, as well.

While mitigation efforts are important in combating global warming and its attendant effects on climate patterns, by going directly to the source of the problem, adaptation responses on the part of farmers have been the main focus of agricultural economists. Farmers are expected to make adjustments to their behavior in order to lessen the impact of climate changes, or to reduce their exposure to increased risk and variability in environmental conditions. If the primary characteristics of climate change are increased variability or frequency of extreme weather phenomena, then the challenges

of adaptation will be even greater for agriculturally-dependent economies that are more susceptible to environmental shocks and weather pattern changes – particularly for those crops that are primarily rainfed.

Kurukulasuriya and Rosenthal (2003) present a matrix of potential adaptation responses to climate change (Table 1).

Many of these adaptation responses take place at the farm-level, as farmers make adjustments to their production behavior in order to accommodate changes in climate conditions, either in terms of the types of crops that they grown, or the technology used on-farm, such as irrigation or drought-resistant seed technologies. Some of these adaptations occur at the household level, where individuals might decide to migrate or otherwise diversify their portfolio of economic activities to lessen their reliance on weather-dependent agricultural income. However, those rural households that are headed by women are particularly vulnerable when the male members of the household migrate, as the women must assume the men's responsibilities, without having full access to the social, financial or technological resources that male-headed households do (Lambrou and Laub, 2004). The tendency for farmers to sell productive assets such as livestock as a response to idiosyncratic shocks has been well-studied within the development economics literature. Among other adaptation responses that can take place at the household level is the adoption of market-supplied instruments or informal arrangements to offset risk in income from agriculture. Where formal market instruments are not available, the development economics literature has also studied the tendency of households to make informal risk-sharing arrangements with other agents to mutually offset their exposure to variability. As McCarthy (2004) notes, however, the effectiveness

of these informal arrangements are limited to fairly localized shocks, and are unable to offer adequate coverage as shocks become more aggregate and spatially correlated.

Other adaptive actions can be taken at the institutional level, so as to reduce the aggregate exposure to increased variability in income and environmental factors. Such measures could include the improvement of water supply infrastructure and irrigation efficiency, so as to enhance the reliability of deliveries to farmers and provide a buffer against increasingly variable rainfall. Other institutional reforms can take the form of market reforms or interventions which can include grain procurements to offset sharp rises in food prices, where markets are poorly integrated or other kinds of price-stabilization measures. Technological innovations that can take place at the institutional level can result from investments in agricultural research that can make drought-resistant seed varieties available to farmers, or from efforts to make climate information more readily available to farmers through early-warning systems. Vosti et al. (2001) have shown, using the example of Mexico, that such early-warning systems can greatly enhance the information available to farmers and help facilitate the socio-economic adjustments needed to adapt to extreme-weather events and their trend of increasing frequency. Crop and weather based insurance are important adaptation strategies currently used in developed countries. Studies have shown a demand for and applicability of insurance in developing countries as well (McCarthy, 2004; Paxson, 1992; Varangis et al., 2004).

Kurukulasuriya and Rosenthal (2003) conclude that while there is a large menu of adaptation options, the actual measures taken would need to relate to the specific context and be well thought out. Measures taken can only relate to the current state of knowledge

about climate variability and climate change. Moreover, national and sectoral policies and international assistance should take expected and real impacts from climate change into account. Climate change adaptation strategies, to be (cost)-effective, should be formulated in the form of incentives and incorporated into project development when it relates to climate change; they need to be flexible, as conditions are unlikely to change in a linear, foreseeable fashion; and while adaptation measures per se do not have to be innovative—farmers and others have been adapting to changing climate over centuries—it is important that incentives that facilitate adaptation are geared towards serving the poorest in increasing their access to food, water, and income.

Towards A Research Agenda for Climate Change for the CPWF

While there are likely avenues for mitigation of climate-changing factors on the part of policymakers in developed countries, the most urgent role of policy intervention on the part of the CPWF seems to be in the way in which adaptive capacity in developing countries can be strengthened. As Pielke (1988) notes, mitigation – by itself – seems an insufficient policy to address climate change concerns and there is expanding dialogue within policy-making arenas to combine mitigation measures with strategies for adaptation to prepare vulnerable economies for climate change impacts (Kurukulasuriya and Rosenthal, 2003). As Kurukulasuriya and Rosenthal (2003) note, the Intergovernmental Panel on Climate Change (IPCC) emphasizes that adaptability – through changes in ‘processes, practices and structures’ – is a key element in reducing adverse impacts of global climate change (IPCC, 2001).

A number of researchers have identified key research questions that should be further explored in order to fully address the need for strengthening the adaptive capability of rural agricultural economies facing impending climate change shocks. These recommendations range from better understanding the dimensions of vulnerability of rural households (Benson, 2004) to examining how better information can improve the ability of households and national governments to adapt to shocks (Zhang, 2004). While some arguments are aimed more at national-level food policy (Wada and Minot, 2004) rather than household adaptive behavior, they each address important components of the close interaction between changes in the natural environment and the rural agricultural

economy. Finally, other strategies need to relate to global and regional policymaking bodies, including the WTO regarding the role of trade in reducing (or increasing) the impacts from climate change and the WHO on health implications from climate change.

As a first step to addressing ways of reducing the vulnerability of rural households to climate shocks, greater research effort should be put into fully understanding the various dimensions of risk exposure and vulnerability to climate change that rural households face. There is currently no global modeling framework capable of tracing the implications of climate change and other global changes on outcomes for water and food security of the rural poor. Moreover, such a global model should be combined with the insights of household-level and national-level studies for adaptation to global climate change. As McCarthy (2004) points out, existing micro-data and results from micro-level studies can be used in a more meaningful way than just through econometric investigations, if they are used to build policy simulation models that can investigate how policy instruments can be used under alternative climate scenarios. Within a simulation framework, combined hydrologic and economic policy models can easily interact with integrated global climate models that can represent environmental conditions and the severity of climatic variability that might be experienced under likely weather scenarios. Such approaches can be found in the studies done by Adams et al. (1999) and Hurd et al. (1999), within the context of the United States – but no such investigations have been done for the agricultural production within developing countries. Exceptions are possibly Vosti et al. (2001) who analyzed the impacts of ENSO on agricultural production in Mexico, Naylor et al. (2001) and Falcon et al. (2004) who examined the impact of ENSO on Indonesian rice production. Thus,

there is an acute shortage of information for those countries that produce the bulk of food today and for those who are the least water- and food-secure. The paucity of integrated, quantitative simulation-based models in the literature underscores the urgency of research efforts on the part of the CPWF to address the pressing policy issues that arise from consideration of the likely impacts of climate change on agricultural livelihoods in developing countries.

Research questions that the CPWF therefore needs to address include

- 1) What is the impact of global change on water cycles?
- 2) What is the impact of global change on water and food supply and demand?

Addressing these research questions is necessary to identify the dimensions of climate change affecting rural dwellers in developing countries.

- 3) What are appropriate policies to reduce adverse human impact from climate change, that is, what are appropriate adaptation strategies at the local, basin, regional, and global levels?
- 4) What policies and strategies can developing countries adopt to contribute to a reduction of climate change?

As noted by Benson (2004), the extensive research that has already gone into describing the vulnerability of the poor to shocks in the economic environment can be applied just as readily to looking at shocks in the physical environment. Once the various levels of risk exposure have been understood (research questions 1 & 2), then researchers can identify the most effective instruments—insurance and other—that can protect the poor from climate shocks, and to define the appropriate mechanisms to deliver those instruments (McCarthy, 2004).

A necessary next step to understanding how to improve the adaptive capacity of poor households is to identify the possible constraints that they might face when trying to make farm-level adjustments to changing environmental and economic conditions. While some of these constraints might be informational in nature, some could be directly related to the availability of economic instruments at the farm level, as well as to limits of the institutional structure of the rural agricultural economy. Other constraints include trade distortions at the international level, and other macroeconomic and sectoral policies, including foreign direct investment policies, national and donor policies regarding funding for agriculture and related infrastructure, and the level of assistance for institution building to enhance resilience to climate variability and change. Of particular importance for adaptation to climate change will be the future role of storage and the potential for investments in storage. Only 5 percent of all registered large dams in the world are located in Africa, where most of the severe economically water scarce countries and the population most vulnerable to climate change, are located (Keller et al., 2000). The goal will be to devise policies and institutions that allow farmers and other rural dwellers to adapt to changes in the climate in the most flexible and least costly ways.

As Zhang (2004) notes, greater effort can be made by researchers to explore how limitations of capital and resource endowments of rural, agricultural households can affect their ability to adapt to climate changes and other related shocks. Along the same vein, Wada and Minot (2004) raise the question of how insurance mechanisms against weather-related shocks can be made practicable in developing countries, and what is the exact role of labor markets in helping farmers to adjust to weather shocks.

On the level of national policy, there are also important adaptation mechanisms that governments can make use of, and to which policy research can address itself more directly. While most severe environmental shocks and socioeconomic disruptions in developing countries have been met with concerted disaster-relief efforts, there has been concern among policy researchers that long-term capacity strengthening has the tendency to be overlooked in favor of the emphasis put on shorter-term response measures and aid. Zhang (2004) makes the point that research is needed to help policymakers evaluate the tradeoff between providing short-term disaster relief to those who suffer from climate shocks and developing the in-country capacity and infrastructure to deal with climate change in the long-term. Also on the level of national policy, Wada and Minot (2004) call into question—in the face of climate change—the trade policy of many national governments towards staple foods, as well as the impact of food aid on the procurement of grain by governments and on the incentives of local traders to engage in food exports. They also raise the need for researchers to investigate the determinants that underlie the tendency of developing countries to restrict food exports during weather-related shocks to agricultural production, and to evaluate the likely distributional consequences of such policies.

Finally, while only 15 percent of the world's population who live in high-income countries emit more than 50 percent of total carbon dioxide and other greenhouse gases that are altering the Earth's climate – it is still also important to devise policies and strategies that would facilitate the contribution of developing countries in climate mitigation. Climate mitigation strategies in these countries would be particularly effective in the agriculture sector, which is the dominant contributor of greenhouse gases

in the developing world (research question 4). In addition to the potential reduction in emissions from alternative production practices, agriculture can serve as a significant sink by sequestering large amounts of carbon in soils, vegetation, and durable goods produced from plants (DOE 1999, Lewandrowski et al. 2004). However, such policies should only be devised if they constitute win-win strategies, that is, developing-country farmers and livestock herders would not lose out from adopting climate-mitigation strategies and/or should be adequately compensated for their efforts by the developed world. This allows developed countries to achieve their climate mitigation goals in a more efficient and cost-effective manner while at the same time supporting agricultural development in developing countries (Metz et al. 2000). Such policies could include direct payments by developed countries to developing countries, linking climate mitigation strategies with trade policies, R&D diffusion policies, and other ancillary health, social, and economic benefits through the transfer of resources to developing countries, or voluntary participation of developing countries in international emissions trading markets (Viguier, 2003). Global 'North-South' policies have been discussed or are in effect for carbon sequestration and emissions abatement through the Clean Development Mechanism (CDM) and other means of technology transfer established by the UNFCCC (2003).

Conclusion

The purpose of this short essay has been to underscore the importance of a concerted agenda for research on the impact of global climate change on developing countries for the CPWF. While much of the literature on climate change, within the context of industrialized countries, has focused on mitigation strategies to reduce the emission of greenhouse gases into the atmosphere, there is a greater need to focus on adaptation strategies when considering the context of developing economies. This change of research emphasis requires a) the development new tools to jointly analyze the impacts of climate change on water and food security, and to model policy responses to climate change, including increased climate variability; and b) it requires researchers to draw on the extensive literature that already exists in the fields of agricultural economics, hydrology, geography, and sociology regarding the responses of rural households to both gradual climate changes and shocks. Through this type of investigation, policy researchers might gain a better understanding of where to aim policy efforts and scarce resources most effectively, so as to improve the resilience of rural agricultural economies to the challenges they will face under imminent changes to the global physical and economic environment.

Table 1: Adaptation Options in Agriculture to Climate Change and Variability

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
Short term				
Crop insurance Private/public programs Formal/informal schemes	Enabling improved risk coverage	Improving access Risk management thru risk reduction and risk sharing Improving supervisory capacity Revising pricing incentives Improving affordability/availability of coverage for catastrophes	Synergies between govt. and private sector in bearing risks Minimizing information asymmetries Establishing enforcement mechanisms Introducing measures for the correct estimation of premiums Innovative schemes should be pursued (e.g. tradable financial assets; catastrophic bonds; weather markets)	Risk averse communities/insufficient collateral High opportunity costs of public funds High monitoring costs (institutional limitations) Adverse selection/moral hazard Need to establish well-functioning producer organizations
Portfolio (Crop/livestock) Diversification Replacement of plant types, cultivars, hybrids and animal breeds with new varieties Alternative production techniques (adjustment of capital and labor inputs) Multi-cropping Mixed farming systems of crops and livestock	Risk-spreading/ Promoting farm-level risk management Increasing productivity Defending against disease, pest	Availability of extension services Financial support/alternatives should be provided by private and public sector Enable mobility of activities Remove subsidies in certain crops/livestock production not conducive to change climatic and resource conditions	Tenure reform to ensure property rights are established Land-use regulations need to be reviewed to enable diversification Education/training/extension services need to be provided	Traditions, lack of awareness, and other limitations (high opportunity costs) may dampen willingness to diversity Over-dependence on government support mechanisms needs to be reduced Need alternatives that maintain quantity and income from production

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
Adjusting Timing of Farm Operations Adjusting cropping sequence Adjusting timing of Irrigation	Reducing risks of crop damage/ maximizing output in light of new conditions	Extension services/ training is necessary Pricing policies have to be reviewed	Mechanisms for the dissemination of agronomic and climate information Institutional support must be strengthened	Investment in collection of climate data and disseminating information required Limitations of existing infrastructure
Changing Cropping Intensity Adjusting fertilizer and other inputs Changing land use practices Changing location of crop/livestock production Rotating or shifting production between crops and livestock Abandonment of land Changing the timing of activities (of sowing, planting, spraying and harvesting) Changing the timing of Irrigation	Improving moisture and nutrient retention Reducing soil erosion Adjusting to changing length of growing season Increasing plant protection	Extension services must be improved Pricing policy adjustments for incentives to making adjustments	Location-specific solutions should be sought	Availability of cultivable land; availability of alternative lands Socioeconomic (financial) Conflicts with other farm operations at other times of the year Traditions, lack of awareness and other limitations (high opportunity costs) may dampen willingness to diversify Concerns regarding maintaining similar production levels
Livestock Management Change in biological diversity, species	Spreading risks; increasing productivity	Provision of extension services	Promoting investment in livestock management	Traditions, lack of awareness, and other limitations (high opportunity costs) may dampen willingness to diversify

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
<p>Altering the breeding management program (i.e. changing composition, or species distribution)</p> <p>Change in grazing management (timing, duration and location)</p> <p>Changing the location of watering points</p> <p>Changes in rangeland management practices</p> <p>Modifying operation production strategies</p> <p>Changing market strategies</p> <p>Implementing feed conservation techniques/ varying supplemental feeding</p>	Adjusting to new climate conditions		Institutional support	
<p>Changes in Tillage Practices (Conservation Tillage)</p> <p>Land contouring and terracing</p> <p>Maintaining crop residues</p> <p>Fallow and tillage practices</p> <p>Planting of hedges</p>	<p>Conserving soil moisture and organic carbon contents and increased soil erosion maintain soil fertility and prevent erosion (nutrient management)</p> <p>Maintaining soil quality/provide protection against wind erosion</p> <p>Increasing production per unit of evapotranspiration</p> <p>Reducing water run-off/improving water uptake</p>	<p>Extension services need to support activities</p> <p>Pricing incentives to promote conservation</p>	<p>Investment</p> <p>Land tenure reform</p> <p>Indigenous knowledge</p>	

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>	
<p>Alternative drainage method</p> <p>Construction of diversions and reservoirs and water storage</p> <p>Irrigation</p> <p>Reducing water use in land preparation</p>	<p>Recharging water supply</p> <p>Reducing runoff and erosion</p> <p>Nutrient restocking</p> <p>Conserving water</p>				
Temporary Migration	Risk diversification strategy to withstand climate shocks and seasonal effects	Employment training/ opportunities	Institutional support	<p>Availability of employment opportunities in urban areas; growth elsewhere in economy</p> <p>Skills and earnings potential</p> <p>High population density in cities</p>	
Short-Term Forecasts	Improve preparation for medium-term climatic impacts	Institutional support for collection and dissemination, information dissemination	Infrastructure for monitoring	Financial resources constraints	
Food Reserves and Storage	Temporary relief		Delivery mechanisms	Expensive/complacency	
Changing Crop Mix	<p>Adopting new crops</p> <p>Planting in different parts of the farm</p> <p>Converting land use</p>	<p>Spreading risk of damage</p> <p>Move away from unstable cash crop systems</p>	<p>Revising pricing; food importation policy</p> <p>Tenure; extension; pricing incentives</p> <p>Improving access and affordability</p> <p>Need viable alternatives (incomes)</p>	<p>Promoting investment</p> <p>Institutional support to administer</p> <p>Agricultural marketing policies</p> <p>Review of agricultural credit schemes</p>	<p>Institutional failures</p> <p>Acceptance of change gradual</p> <p>Economic failures (maintaining incomes)</p> <p>Knowledge</p>
Irrigation	Increase productivity; withstand rainwater shortages	Investment by public and private sectors	Clear water management policy	Institutional support and enforcement mechanisms	

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
<p>Modernization of Farm Operations</p> <p>Research and development (biological and mechanical options)</p> <p>Adoption of technology (e.g. use of sprinklers)</p>	<p>Increase productivity</p> <p>Withstanding climate effects</p>	<p>Promoting the adoption of technological innovations</p>	<p>Establishment of intellectual property rights</p> <p>Role of private multinationals</p>	<p>Conflicts between national/private objectives</p> <p>Maintaining similar production levels</p> <p>Subsidization programs may create perverse incentives</p>
<p>Permanent Migration</p>	<p>Diversify income-earning opportunities</p> <p>To overcome long lasting climate impacts</p>	<p>Education and training for alternative opportunities</p> <p>Retraining</p>	<p>Institutional support (property rights)</p>	<p>Impacts on resource base</p> <p>Land pressure</p>
<p>Defining Landuse and Tenure Rights</p>	<p>Incentives to make necessary investments in agricultural land to withstand climatic impacts</p>	<p>Legal reform and enforcement</p>		
<p>Efficient Water Use</p> <p>Improving water distribution</p> <p>Promoting irrigation efficiency</p> <p>Changing crop and irrigation schedules</p> <p>Water recycling and the conjunctive use of groundwater</p> <p>Rehabilitation and Modernization</p>	<p>Water conservation</p> <p>Avoid salinization; increase in moisture retention</p> <p>Water storage and flood control</p>	<p>Pricing reforms for water</p> <p>Clearly defined property rights</p> <p>Develop open markets</p> <p>Strengthening farm level managerial capacity</p>	<p>Sustainable water projects</p> <p>Diffusion of technological advances in water</p> <p>Institutional reforms</p>	<p>Cost</p> <p>Competing demands</p> <p>Financial crises</p> <p>Low-cost recovery of the investment in the water system</p> <p>Political economy issues</p>

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
Both short- and long-term				
Investment Promotion	Overcome financial limitations to adapt	Property rights; designing innovating financial tools Injection of initial capital		Social constraints against capital accumulation Reluctance of agricultural traders to offer inputs on credit
Develop Market Efficiency Pricing reform Develop open markets Reform of agricultural Markets	Promote more efficient use of resources	Remove barriers Property rights; pricing policy Adjustment of agriculture input subsidies that constrain adaptation Land use regulations	Institutional support The establishment of regional consultation centers Impart knowledge on adaptation alternatives	Poor transport infrastructure
Adoption of Technological and Other Adaptation Measures	Increasing agricultural yields Reducing average fixed costs Reducing variable costs	Pricing incentives/ tax reform Extension services for training Finance schemes	Community management and cooperation programs	Natural constraints – if land is available Socioeconomic capacity to adapt Complete removal of government support Lower producer prices; lower world food prices Attitudes towards risk Level of uncertainty of the future Availability of funds for investment Access to assets, capital, and credit High tariffs in export markets

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
Promoting Trade	<p>Promoting economic growth</p> <p>Strengthening long-term food supply and production limitations</p> <p>Reducing risks of food shortages</p>	<p>Pricing and exchange rate reform and stabilization</p> <p>Adjustment of agricultural subsidies and tariffs</p>	Social policy	Subsidies in developed markets
Developing Extension Services	<p>Improve agricultural productivity</p> <p>Improve awareness and knowledge of measures</p>	<p>Role of private, non-governmental and cooperative agencies</p> <p>Ensuring sufficient agents per farmer/region</p>	<p>Ensure agents are productive through adequate incentives</p> <p>Limit/remove management failures</p> <p>Public organization, resources, and institutional support</p> <p>Utilize indigenous knowledge</p>	
Improving Forecasting Mechanism	<p>Assist planning</p> <p>Strengthen ability of to cope</p>	<p>Extension</p> <p>Institutional support (e.g. establishment of farmer cooperatives to spread knowledge)</p>	<p>Information needs to be distributed across all sectors</p> <p>Horizontal and vertical exchanges of information</p> <p>Ensure information is in a usable form</p>	<p>Financial</p> <p>Conflicts with traditional practices/ social conventions</p> <p>Skepticism</p>

<i>Adaptation option</i>	<i>Purpose</i>	<i>Necessary supporting policies</i>	<i>Other prerequisites</i>	<i>Limitations</i>
Institutional Strengthening and Decision-Making Structures	<p>To support long term planning</p> <p>Reduce vulnerability</p> <p>Provide information on the changing socioeconomic structure, demographics, technology and public preferences</p> <p>Improving organization capacity, responsibility and operational effectiveness</p>	<p>Reform existing institutions that support agricultural sector</p> <p>Pricing incentives: improving regulations and technology standards</p> <p>Legal infrastructure (reform) for stimulating domestic and international investments</p> <p>Changes in international and domestic competition</p> <p>Social policies</p> <p>Upgrading of current physical planning laws and regulations</p>	<p>Participation of key stakeholders</p> <p>Requires integrated management practices; need to fit specific institutional settings</p> <p>Comprehensive multi-sectoral management plans</p> <p>Resilience; flexibility; public education program</p> <p>Remove bureaucratic inefficiencies</p> <p>Equally well functioning institutions in other sectors</p> <p>Improve coordination between central and local government</p>	<p>Planning agencies formed by administrative resolution as opposed to being mandatory</p>

References

- Adams, R.M., J.D. Glycer, B.A. McCarl and D.J. Dudeck (1988): "The Implications of Global Climate Change for Western Agriculture." *Western Journal of Agricultural Economics* 13: 348-356.
- Adams, R.M., C. Rosenzweig, J. Ritchie, R. Peart, J.D. Glycer, B.A. McCarl, B. Curry and J. Jones (1990): "Global Climate Change and U.S. Agriculture." *Nature* (May, 1990): 219-224.
- Adams, R.M., B.A. McCarl, K. Segerson, C. Rosenzweig, K.J. Bryant, B.L. Dizon, R. Conner, R.E. Evenson and D. Ojima (1999): "Economic Effects of Climate Change on US Agriculture." Chapter 2 in *The Impact of Climate Change on the United States Economy* (R. Mendelsohn and J.E. Neumann, eds.), Cambridge University Press.
- Benson, T. (2004): "IFPRI Draft Proposal for Global Climate Change Centered Research: Effects and Adaptive Strategies." *Paper contributed to the report for the Task Force on Global Climate Change*, International Food Policy Research Institute, Washington, D.C.
- DOE (United States Department of Energy) 1999. Emission and Reduction of Greenhouse Gases from Agriculture and Food Manufacturing: a Summary White Paper. DOE, Office of Energy Efficiency and Renewable Energy, Office of Industrial Technologies, Washington, D.C.
- Falcon, W.P., R.L. Naylor, W.L. Smith, M.B. Burke, E.B. McCullough. 2004. Using climate models to improve Indonesian food security. *Bulletin of Indonesian Economic Studies*, 40(3): 355 – 377.
- Hurd, B., M. Callaway, J.B. Smith and P. Kirshen (1999): "Economic Effects of Climate Change on US Water Resources." Chapter 6 in *The Impact of Climate Change on the*

United States Economy (R. Mendelsohn and J.E. Neumann, eds.), Cambridge University Press.

IPCC (2001): "Climate Change 2001: Impacts, Adaptation and Vulnerability."

Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, available at:
http://www.grida.no/climate/ipcc_tar/wg2/ .

Keller, A., R. Sakthivadivel, and D. Seckler (2000): "Water Scarcity and the Role of Storage in Development" *IWMI Research Report 39*, IWMI, Colombo, Sri Lanka.

Kurukulasuriya, P. and S. Rosenthal (2003): "Climate Change and Agriculture: A Review of Impacts and Adaptations." *Paper no. 91 in Climate Change Series*, Department of the Environment, The World Bank, Washington, D.C.

Lambrou, Y., and R. Laub (2004): "Gender Perspectives on the Conventions on Biodiversity, Climate Change and Desertification." *Discussion*, FAO Gender and Population Division, Food and Agricultural Organization, Rome.

Lewandrowski, J.; C. Jones; R. House; M. Peters; M. Sperow; M. Eve; K. Paustian. 2004. Economics of Sequestering Carbon in the U.S. Agricultural Sector. Technical Bulletin 1909. United States Department of Agriculture Economic Research Service, Washington, D.C.

Metz, B.; O. Davidson; J.W. Martens; S. Van Rooijen; and L. Van Wie McGrory (Eds.) 2000. Methodological and Technological Issues in Technology Transfer: Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

McCarthy, N. (2004): "Risk and Insurance." *Paper contributed to the report for the Task Force on Global Climate Change*, International Food Policy Research Institute, Washington, D.C.

Mendelsohn, R., W. D. Nordhaus and D. Shaw (1994): "The Impact of Global Warming on Agriculture: A Ricardian Analysis." *American Economic Review* 84: 753-771.

Mendelsohn, R., W. Nordhaus and D. Shaw (1999): "The Impact of Climate Variation on US Agriculture." Chapter 3 in *The Impact of Climate Change on the United States Economy* (R. Mendelsohn and J.E. Neumann, eds.), Cambridge University Press.

Mendelsohn, R., and A. Dinar (1999): "Climate Change, Agriculture, and Developing Countries: Does Adaptation Matter?" *The World Bank Research Observer* 14(2): 277-93.

Mendelsohn, R. (2000): "Measuring the Effect of Climate Change on Developing Country Agriculture." In *Two Essays on Climate Change and Agriculture*, FAO Economic and Social Development Paper no. 145, FAO, Rome.

Naylor, R.L., W.P. Falcon, D. Rochberg and N. Wada (2001): "Using El Nino/Southern Oscillation Climate Data to Predict Rice Production in Indonesia" *Climate Change*, 50: 255-265.

Paxson, C.H. (1992): "Using Weather Variability to Estimate the Response of Savings in Transitory Income in Thailand." *American Economic Review*, 82: 15-33.

Pielke, R. A. (1998): "Rethinking the Role of Adaptation in Climate Policy." *Global Environmental Change*, 8(2): 159-170.

Raskin, P., E. Hansen and R. Margolis (1995): "Water and Sustainability: A Global Outlook." *Polestar Series Report no. 4*, Stockholm Environmental Institute, Boston, Massachusetts.

Raskin, P., P. Gleick, P. Kirshen, G. Pontius and K. Strzepek (1997): "Water Futures: Assessment of Long-Range Patterns and Problems." *Background Document for Chapter*

3 of the Comprehensive Assessment of the Freshwater Resources of the World,
Stockholm Environmental Institute, Boston, Massachusetts

Reilly, J., Tubiello, F., McCarl, B., Abler, D., Darwin, R., Fuglie, K., Hollinger, S., Izaurrealde, C., Jagtap, S., Jones, J., Mearns, L., Ojima, D., Paul, E., Paustian, K., Riha, S., Rosenberg, N., & Rosenzweig, C. (2002). "Agriculture: The Potential Consequences of Climate Variability and Change." Cambridge, UK: Cambridge University Press.

Rosegrant, M.W., X.M. Cai and S. Cline (2002): "World Water and Food to 2025: Dealing with Scarcity." International Food Policy Research Institute, Washington, D.C.

Rosenzweig, C. and D. Hillel (1998): "Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture." Oxford University Press.

United Nations Framework Convention on Climate Change (UNFCCC). 2003. Report of the Executive Board of the Clean Development Mechanism. Conference of the Parties, 9th Session, Milan.

Varangis, P., J. Skees, and B. Barnett (2004): Weather Indexes for Developing Countries. In *An Adaptation Mosaic. A Sample of the Emerging World Bank Work in Climate Change Adaptation*. Final Draft, eds. A. Mathur, I. Burton, and M. van Aalst, World Bank, Washington, D.C.

Viguiet, L. (2003): Defining meaningful participation of developing countries in climate change mitigation. *NCCR-WP4 Working Paper 17*. Swiss National Centre of Competence (NCCR) "Climate" Work Package 4: "Climate Risk Assessment" University of Geneva & Paul Scherrer Institute. Accessed at http://ecolu-info.unige.ch/~nccrwp4/wp4.17_bis.pdf

Vosti, S.A., R.L. Harris and M. Glave (2001): "Feasibility Study on the Prediction and Amelioration of Socio-economic Impacts of El Nino/Southern Oscillation (ENSO) in

Latin America and the Caribbean.” Report No. ATN/JF-6579-RG, University of California, Davis.

Wada, N. and N. Minot (2004): “Climate Change and the Implications for Agricultural Markets.” *Paper contributed to the report for the Task Force on Global Climate Change*, International Food Policy Research Institute, Washington, D.C.

Yan, N. (2004): “Global Mitigation Strategies and Carbon Programs.” *Paper contributed to the report for the Task Force on Global Climate Change*, International Food Policy Research Institute, Washington, D.C.

Zhang, X.B. (2004): “Climate Change and Adaptation.” *Paper contributed to the report for the Task Force on Global Climate Change*, International Food Policy Research Institute, Washington, D.C.