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Global Impacts of Climate Change on Water, Agriculture and Food, and Implications for South Asia

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1. Introduction

Asian and global agriculture will be under severe pressure to meet the demands of rising populations, using finite and often degraded soil and water resources that are predicted to be further stressed by the impacts of climate change. In addition, agriculture and land use change are prominent sources of global greenhouse gas (GHG) emissions. The application of fertilizers, rearing of livestock, and land management affects levels of GHG in the atmosphere and the amount of carbon storage and sequestration potential. The continued release of GHG and their impending impacts on climate will have negative effects on agricultural production in parts of Asia as well as the rest of the world. Thus, it is critical for stakeholders in the agricultural sector to understand the impacts that climate change will have on food and crop production. There will undoubtedly be shifts in agroecological conditions that will warrant changes in processes and practices to meet daily food requirements. Moreover, for net food importing countries like some in South Asia (Bangladesh, Pakistan), who continue to struggle to meet daily food requirements, climate change will become more salient as a production constraint.

In this paper, the impacts of climate change on food production were briefly reviewed with a focus on South Asia, including implications for food security and poor livelihoods. It will highlight the impacts related to food production—namely crop and livestock production. It will consider how the release of carbon and GHG will impact the agricultural sector, drawing heavily on future climate projections focusing on South Asia as well as the impacts of agricultural production on global warming. The objective is to provide a synthesis of the evidence on the impacts of agriculture on climate change, as well as the impacts climate change is projected to have on this sector.

2. Climate Change and Agriculture, with emphasis on South Asia

Projected changes in temperature and other climate functions will impact agroecological conditions and food production at the global and regional levels. As a result, farmers will need to adjust technologies and practices to continue to meet food requirements. However, adapting to new climate scenarios may not be feasible in all situations. A lack of adaptive capacity due to constraints on resources, such as access to weather forecasts or better seed varieties, may result in further food insecurity. To better prepare vulnerable regions, climate scientists and economists are using integrated assessment models to identify high-risk regions and crops, as well as the resulting socioeconomic impacts. In this section, the model results are presented, along with the key uncertainties.

Impacts on Food Production Systems

Rapidly rising levels of CO_2 and other GHG in the atmosphere have direct effects on agricultural systems due to increased CO_2 and ozone levels, seasonal changes in rainfall and temperature, and modified pest, weed, and disease populations. In general, the flux of agroclimatic conditions can alter the length of growing seasons, planting and harvesting calendars, water availability and water usage rates, along with a host of plant physiological functions including evapotranspiration, photosynthesis and biomass production, and land suitability. Due to the number of variables involved and the chaotic nature of weather systems, predictions are not meant to be taken as what will happen, but rather describe the range of possible outcomes that can be expected.

Integrated Assessment Models for Food Systems under Climate Change

Model-based frameworks have been developed that forecast short- and long-term impacts on food systems. The majority of models investigate regional impacts, although relatively fewer models are dedicated to predicting impacts on developing country agriculture. Several specific modeling applications are required in characterizing the possible effects of climate change on crop yield and production, and their subsequent impacts on food prices and food security. Generally, a combination of a crop model, climate simulation model, and world food trade model are implemented under predictions of GHG emission rates and socioeconomic development. These component models combine to create integrated physiological-economic models.

Warming across the Asian continent is anticipated but will be unevenly distributed. The general trajectory will depend on global emissions scenarios, but impacts will depend critically on local manifestations. The average results across a collection of global circulation models in terms of global averages and the associated global distributions for three SRES (Special Report on Emission Scenarios) scenarios for the 2020s and the 2090s were analyzed (IPCC 2007). These temperature portraits were translated into assessments of sectoral vulnerabilities for sub-continental regions distributed across Asia, as shown in Table 1 (Cruz et al. 2007). The results show that eco-systems in South Asia and Asia more generally, are highly vulnerable to the effects of climate change.

Impacts on yield and production

Carbon fertilization

Cline (2007) shows strongly negative impacts on most developing countries and also demonstrates the effect of carbon fertilization on agricultural productivity—measured in net revenue changes—by regions (Figures 1 and 2). For example, India may actually face agricultural losses of almost 40 percent without carbon fertilization, although this can be reduced to 29 percent with CO_2 fertilization in 2080. The northeast part of the country is in a much worse scenario as agricultural productivity can decline to as much as 44 percent if CO_2 fertilization does not materialize. On the other hand, China is in a better position. The south central region needs to address a 15 percent drop in agricultural productivity without fertilization, although the aggregate effects at the national scale will be about -7 to 7 percent. Table 2 presents the change in agricultural productivity with and without CO_2 fertilization in 2080.

Warren (2006) studied the impacts of climate change on cereal yields using simulation of percentage reductions in major crop yields in the presence or absence of CO_2 fertilization and under increased temperature for sub-regions in Asia. Analysis showed that wheat yields will decline 30–40 percent in Western Asia with a temperature rise of 3–4^{o}C globally above 1990 levels, should CO_2 fertilization not occur. Losses occur at 20–30 percent in Central Asia and

East Asia, while 10–20 percent is estimated in South Asia. With CO_2 fertilization, losses are roughly 50 percent smaller.

For the same study, without CO_2 fertilization, Central Asia will lose 20–25 percent in rice yields, while South and East Asia will lose 10–20 percent in rice yields at a temperature rise of 3–4^{o}C above 1990 levels. With CO_2 fertilization, increases in yield of 1 to 2 percent can occur at a temperature rise of 2–3°C, and increases may take place in many regions, except Central Asia, where losses still occur. However, at the higher increase of 3–4°C, global yield reductions of around 3 percent still occur as temperature effects trump CO_2 fertilization. Central, South, and West Asia will have a 20–30 percent decline in maize yields, while East Asia will experience a 10-20 percent decrease in yields at a 3–4^{o}C temperature increase without CO_2 fertilization. Nonetheless, a 16 percent reduction in yields was still estimated in Central Asia, even with CO_2 fertilization. Maize is a C4 plant and thus responds less to CO_2 fertilization.

IFPRI's work simultaneously assesses the impacts of climate change on food production and food prices. Figure 3 shows the percentage change in wheat yield in 2050 as a result of climate change, assuming the HadCM3-SRES B2 climate change scenario, projected by the IMPACT[1] global food and water model. India is projected to experience substantial wheat yield reductions. These reductions will occur despite significant increases in wheat prices due to climate change (Figure 4). By 2050, it is projected that the world wheat price under climate change will be about 40 percent higher than the reference scenario assuming climate change does not take place. Consumers will therefore absorb much of the impact of climate change.

China and India

As the two countries with the largest populations and areas in Asia, China and India may significantly impact the rest of the countries in Asia and the world through international trade of agricultural commodities as climate change affects their agricultural production. A number of studies have evaluated agricultural production in the two countries under climate change.

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[1] IMPACT – International Model for Policy Analysis of Agricultural Commodities and Trade. Details can be found in Rosegrant et al. 2008 at http://www.ifpri.org/themes/impact/impactwater.pdf.

China. Tang et al. (2000) found that average land productivity grew from 1.5 to 7 percent under irrigated conditions, and from 1.1 to 12.6 percent in rainfed conditions from the 2020s to 2080s using HadCM2, CGCM1, and ECHAM4 scenarios. Another study looked at the impact on cereal yield using PRECIS[2] of the HADLEY Center. Assuming an absence of land use pattern, water supply, and pest and disease turbulence, results indicated that without CO_2 effects, the yield of all rainfed crops will decline (wheat: 12–20 percent; maize: 15–22 percent; and rice 8–14 percent) compared to baseline rainfed crops by 2050. With irrigation, a lesser decline will take place: wheat by 3–7 percent; maize by 1–11 percent; and rice by 5–12 percent (Ju et al. 2005; Xiong et al. 2005).

Lin et al. (2006) studied the monetary value of climate change impacts on rice, wheat, and maize. Considering changes in the inflation rate and agricultural product price trends since the 1980s, the assumption was made that in the next 15 years, price indices of rice, wheat, and maize will remain around 105 percent (104-106 percent), and the current crop planting time and planting varieties remain the same. Given these conditions, the corresponding economic impact estimations of changes due to climate change in average crop production by 2020 compared to the base period of 1961–1990 are given in Tables 3, 4, and 5. Without CO_2 fertilization, outputs of the three crops will diminish under the A2 and B2 scenarios due to climate change, while lower outputs will be produced under rainfed conditions. For the B2 scenario under rainfed conditions, rice, maize, and wheat production will decrease by 5.3 percent, 11.3 percent, and 10.2 percent respectively without CO_2 fertilization. This corresponds to direct economic losses of ¥24.7 billion for rice, ¥19.9 billion for maize, and ¥21.3 billion for wheat, accounting for 1.84 percent of GDP in 2020.

India. Govindasamy, Caldeira and Duffy (2003) assessed the effect of heat due to climate change on wheat yields in India, with a doubling of CO_2. Under this scenario, they found a 51 percent decrease in the most favorable and high yielding regions due to heat stress, thereby leading to likely wheat yield losses. Another study conducted by Roy (2006) analyzed the impacts of climate change by using RCM[3], SWAT[4], and BIOME4[5] models[6]. Some results of simulations on cereal crops show a small positive effect on rice, with a 20

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[2] Providing Regional Climates for Impact Studies

[3] Regional Climate Model

[4] Soil and Water Assessment Tool

[5] Biogeochemistry-Biogeography model

[6] See Roy 2006 for detailed discussions of the models.

percent yield increase in South India according to Saseendran et al. (1999). The same result was found by Roy (2006), where rice has higher yield increases of 5–20 percent until 2070, due to a large increase in CO_2 compared to a relatively small reduction in yield during summer (0.10–0.30^{o}C increase in temperature). Moreover, Roy (2006) found that wheat yield changes could be positive (up to a 25 percent increase) with low rates of change in temperature, but negative (up to a 30 percent decline) with the magnitude of change in CO_2 and temperature projected in the most recent IPCC assessments. Productivity of wheat and other winter crops will decrease substantially with higher temperatures during the winter months.

Impacts on water

Climate change would affect both the demand and availability of water in irrigated agriculture. With higher atmospheric temperature, crops generally require more water for evapotranspiration to maintain healthy growth although higher carbon dioxide level in the air tends to improve crop water use efficiency. On the other hand, altered hydrological regime due to climate change leads to changes in the amount and timing of streamflow and groundwater recharge, with important implications for the performance and sustainability of irrigation, the single largest user of water in the foreseeable future. Even without considering climate effects, 2.5 billion people are expected to be affected with water stress and scarcity in South Asia by the year 2050 (HDR 2006).

The preliminary analysis of irrigation water supply reliability (IWSR) for the South Asia region was done by using the HadCM3/B2 climate change scenario using the IMPACT model. As an indicator of water scarcity, IWSR is defined as the ratio of projected actual irrigation water supply to irrigation requirement. As shown in Figure 5, South Asia region in total is projected to have lower IWSR in 2050, no matter whether climate change would impose a major impact on irrigation water use. However, the impacts are not homogeneous over the entire region. For instance, India is expected to have reduced IWSR without climate change, mostly due to increased water demand and the increasing intensive competition for water from non-agricultural sectors. Under the HadCM3/B2 scenario, irrigation water supply situation would become significantly worse. The rest of South Asia excluding India also shows IWSR decline over time, however, this analysis indicates that these areas may have slightly higher relative water supply due to changes in rainfall patterns. Interestingly, IWSR in Other South Asia region tends to benefit from climate change under the HadCM3/B2 scenario used in this study (Figure 5). This is largely caused by increased precipitation and water availability in Pakistan, a country with the second largest irrigated areas in the region, after India. During the period of 2000 through 2050, there is a pronounced upward trend of precipitation in Pakistan, including the part of Indus River Basin within the country, according to statistically downscaled precipitation data for the HadCM3/B2 scenario by the CRU (Mitchell et al. 2004). As a result, runoff is also predicted to increase by 2050 under this scenario, although increasing temperature pushes up crop water requirements. As a caveat, we acknowledge that analyses using other scenarios and GCM might lead to different findings, which will be explored in future work.

Socioeconomic and food security implications

Future food availability depends on a number of factors in addition to climate impacts on production, including trade policy, food aid, and storage capacity. Food security futures are predicted by making assumptions about trade policy and other aspects of socioeconomic development and integrating them with the results of crop and general circulation models. Currently, however, only one economic model has been used to predict impacts on food security, albeit under different crop models (Schmidhuber and Tubiello 2007). These different crop model results are presented in Fischer et al. (2005) and Parry et al. (2004), both using the Basic Linked System of National Agricultural Policy Models (BLS). Schmidhuber and Tubiello (2007) synthesize the results of these models and estimate that an additional five to 170 million people will be malnourished by 2080, depending on the SRES scenario. Yet Parry et al. (2004) have shown that the regional variation in the number of food insecure people is better explained by population changes than climate impacts on food availability. As a result, economic and other development policies will be critical in influencing future human well being.

Impact of Agriculture on Climate Change

Agriculture—together with related emissions from land use change and forestry—comprise nearly one third of global GHG emissions. Agriculture alone contributed 13 percent of total global GHG emissions in 2000. Emissions from agriculture come from four principal sectors:

agricultural soils, livestock and manure management, rice cultivation, and the burning of agricultural residues and savanna for land clearing. The largest shares of emissions originate from agricultural soils (N_2O) and enteric fermentation and manure management (CH_4) associated with livestock production. Emissions from agriculture are expected to rise due to increased demand for agricultural production from growing populations and improved nutrition and changes in diet preferences that favor larger shares of meat and dairy products (e.g. Delgado et al. 1999). This will also lead to increased pressure on forests due to agricultural expansion.

Regional variations in emissions from agricultural sources (non-CO_2) indicate that Asian countries account for 37 percent of total world emissions from agricultural production where China contributes over 18 percent of the total (WRI 2008). Smith et al. (2007a) further analyzed the contributions of agriculture to GHG emissions by sector in 2005. At the sectoral level, N_2O from soils has the highest emission level, at 44 percent of Asia's total, followed by CH_4 from enteric fermentation at 31 percent. Fertilizer and manure applied in soil were the main sources of N_2O, whereas the large livestock population contributed to the high enteric fermentation that releases CH_4 gas (USEPA 2006). Most developing countries are agriculture based; thus, N_2O from soil ranked as the top emitter of GHG. Furthermore, CH_4 from rice was found to be highest in East and South Asia, at 29 and 13 percent of the region's total respectively. China and India are the two top rice producer countries at the global scale (Maclean et al. 2002) and thus produce elevated levels of CH_4 emissions.

Summary of Impacts

Overall, the clearest conclusion is that climate change will have highly varying and unpredictable impacts on agricultural production in Asia. The estimated impacts depend on the crop, the degree of warming, the assumptions regarding the degree of carbon fertilization and adaptation, and the modeling approach taken. Despite the uncertainty, the weight of evidence indicates that the impact on agricultural production is likely to be most negative in South Asia and Central and Western Asia. Other regions in Asia will likely face declines in wheat, rice, and maize yields, although these will be smaller than in South Asia, and parts of China and East Asia may have slight increases in production for some crops. Globally, agricultural production will likely decline due to climate change, resulting in higher food prices. As a result, food consumers will face higher prices and poor consumers especially will face reductions in food security and well-being.

3. Policy Responses: Adaptation and Mitigation

The range of potential negative predictions may be buffered by adaption measures, or adjustments in natural resource management practices in response to a perceived vulnerability. In response to changing temperatures or rainfall patterns, farmers may need change planting dates or seed varieties. Other short-term measures include changes in tillage practices or adjusted livestock breeds. Long-term changes in management could be improved water management or the creation of irrigation systems.

Supporting policies to stimulate adaptation measures can help to implement these activities more effectively. Adaptation policy is in many cases an extension of development policy that seeks to eradicate the structural causes of poverty and food insecurity. The complementarities between the two will enable a streamlined approach toward achieving both adaptation and poverty alleviation goals. General policies that should be supported include promoting growth and diversification, strengthening institutions, protecting natural resources, investing in research and development, education and health, creating markets in water and environmental services, improving the international trade system, enhancing resilience to disasters and improving disaster management, and promoting risk-sharing, including social safety nets and weather insurance.

Adaptation options and their supporting policies should be adopted by the appropriate level of government and implemented by institutions in direct contact with beneficiaries. For example, adaptation responses such as changing planting dates and tillage practices may require technical services provided by local extension agents and coordinated by regional universities and research institutions. Agricultural research, including crop breeding to develop drought and heat tolerant crop varieties, will require both public and private investment. Structural adaptation measures, such as creating water markets and price incentives, will need to be implemented on a national level, most likely in partnership with economic cooperation unions.

Global scale assessments will be integral in highlighting intra-regional variation in the benefits of adaptation, which in turn will enable more and better targeting of funds. For example, (Lobell et al. 2008) have helped to identify potential food insecure regions as a means of prioritizing investment needs. They have found that 95 percent of models predict that climate change will depress yields to some extent for South Asian wheat, Southeast Asia rice, and Southern Africa maize, which also are the “more important” regions and crops in terms of threat to food security. As a result, resources devoted to adapting the production of these key crops will likely have the greatest benefit.

Emissions abatement in the agricultural sector will also be an important response both as a means of reducing the future impacts of climate change, and as a way to generate foreign exchange in the form of payments for environmental services. Assessments of the technical or theoretical potential for GHG mitigation in agriculture in developing countries by 2030 indicates significant opportunities for reduction in GHG, together with income earning potential for farmers and co-benefits from reduction of natural resource degradation. Developing countries are estimated to account for three-fourths of global technical potential, with Asia accounting for 40 percent, Africa 18 percent, and Latin American and Caribbean 15 percent (Smith et al. 2007a, b).

The economic potential for mitigation in agriculture depends on the price of carbon and on policy, institutional, and transaction cost constraints. It is estimated that the economic potential is about 36 percent of technical potential at carbon prices of carbon prices up to $25 per t CO2-eq, 44 percent at prices up to $50/t CO2-eq, and 58 percent at prices up to $100/t CO2-eq (Smith et al. 2007a, b). Based on the results from USEPA (2006), rice cultivation mitigation strategies have the highest economic potential for emissions reduction in developing countries, especially in Asia; however Smith et al. (2007a, b) find that soil carbon sequestration has the highest economic potential, with the greatest potential in developing countries.

A final word should be given concerning the synergies between adaptation and mitigation. Practices that increase the resilience of production systems may also reduce emissions or sequester carbon. In general, strategies to conserve soil and water resources, such as restoring degraded soils, agro-forestry, and biogas recovery, also enhance ecosystem functioning, providing resilience against droughts, pests, and other climatic threats. However, adaptation can also come at the expense of mitigation, for example when increased use of nitrogen fertilizer to increase food production also increases nitrous oxide emissions. In order to maximize synergies and reduce tradeoffs, mitigation and adaptation strategies should be developed together, recognizing that in some cases hard decisions will need to be made between competing goals.

4. Conclusions and Policy Considerations

This paper presented a brief review on the state of knowledge on climate change and agriculture. In general, agriculture impacts climate change significantly through livestock production and the conversion of forest to land cover that has low carbon sink or sequestration potential. Nitrous oxide emissions from crop production and methane from rice production are also significant. Mitigation options that are the most technically and economically feasible include better cropland and pasture management.

Climate change will also likely have significant negative impacts on agricultural production, with the greatest reductions being in parts of the developing world. Adaptation, including crop choice and timing, has the ability to partially compensate for production declines in all regions. While these predictions have been shown across a number of models, there is a range of specific regional effects and insufficient consideration of multiple stresses, such as extreme weather events, pests, and diseases. In addition, there have been no studies to date on some of the important crops for the rural poor, such as root crops and millet, regarding climate change and carbon fertilization effects.

As a result of changes in production due to climate change, food security will be affected, although socioeconomic policy, especially trade liberalization, can compensate for some of the negative impacts. Climate change alone is expected to increase the number of projected food insecure people by an additional 50 million children by 2050 in South Asia.

To facilitate these roles, global scale assessments should be conducted to identify intra-regional variations in the effects of climate change. These studies will elucidate the range of outcomes possible under plausible climate and adaptation scenarios, which will assist in targeting high priority areas. Once priority areas have been identified, evaluation criteria should be applied that consider not only the net economic benefits, but also the environmental and social appropriateness. In addition, adaptation measures should maximize the complementarities between existing rural and sustainable development objectives.

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Tables

Table 1. Sectoral vulnerability for key sectors for sub-continental regions in Asia

Sub-regions	Food and fiber	Biodiversity	Water resources	Coastal ecosystem	Human health	Settlements	Land degradation
North Asia	+1/H	-2/M	+1/M	-1/M	-1/M	-1/M	-1/M
Central Asia and West Asia	-2/H	-1/M	-2/VH	-1/L	-2/M	-1/M	-2/H
Tibetan Plateau	+1/L	-2/M	-1/M	N/A	No info	No info	-1/L
East Asia	-2/VH	-2/H	-2/H	-2/H	-1/H	-1/H	-2/H
South Asia	-2/H	-2/H	-2/H	-2/H	-2/M	-1/M	-2/H
Southeast Asia	-2/H	-2/H	-1/H	-2/H	-2/H	-1/M	-2/H

Vulnerability: -2 = Highly vulnerable
-1 = Moderately vulnerable
0 = Slightly or not vulnerable
+1 = Moderately resilient
+2 = Most resilient

Level of confidence: VH = Very high
H = High
M = Medium
L = Low
VL = Very low

Source: Cruz et al. 2007

Table 2. Agricultural impacts in Asia with and without carbon fertilization, 2080

	Base Output (US$ billion 2003)	Population (million)	Change in Agricultural Potential (%)	
			Without carbon fertilization	With carbon fertilization
Asia	500	3,362	-19.3	-7.2
China	213	1,288	-7.2	6.8
India	132	1,604	-38.1	-28.8
Indonesia	35	215	-17.9	-5.6

Source: Warren 2006

Table 3. China's rice output change and the average value change in the 2020s

		With CO_2 fertilization		Without CO_2 fertilization	
		Average yield change (%)	Value change (¥ billion)	Average yield change (%)	Value change (¥ billion)
A2[7]	Rainfed	2.1	9.8	-12.9	-60.1
A2	Irrigated	3.8	17.7	-8.9	-41.4
B2[8]	Rainfed	0.2	0.9	-5.3	-24.7
B2	Irrigated	-0.4	-1.9	-1.1	-5.1

Source: Lin et al 2006

Table 4. China's maize output change and the average value change in the 2020s

		With CO_2 fertilization		Without CO_2 fertilization	
		Average yield change (%)	Value change (¥ billion)	Average yield change (%)	Value change (¥ billion)
A2	Rainfed	9.8	17.2	-10.3	-18.1
A2	Irrigated	-0.6	-1.1	-5.3	-9.3
B2	Rainfed	1.1	1.9	-11.3	-19.9
B2	Irrigated	-0.1	-0.2	0.2	0.4

Source: Lin et al 2006

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[7] One of the two major emissions scenarios in IPCC SRES: Uneven global economic development, increasing world population, and medium-high levels of GHG emissions.

[8] One of the two major emissions scenarios in IPCC SRES: Regional sustainable development, slowly increasing world population, and low-medium levels of GHG emissions.

Table 5. China's wheat output change and the average value change in the 2020s

		With CO_2 fertilization		Without CO_2 fertilization	
		Average yield change (%)	Value change (¥ billion)	Average yield change (%)	Value change (¥ billion)
A2	Rainfed	15.4	32.1	-18.5	-38.6
A2	Irrigated	13.3	27.7	-5.6	-11.7
B2	Rainfed	4.5	9.4	-10.2	-21.3
B2	Irrigated	11	22.9	-0.5	-1

Source: Lin et al 2006

Figures

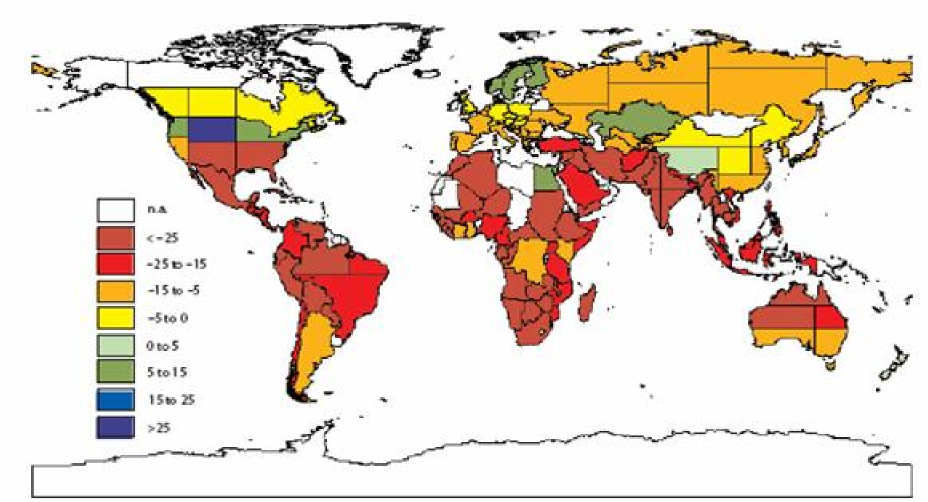

Figure1. Impact on agricultural productivity without carbon fertilization (%)

Source: Cline (2007)

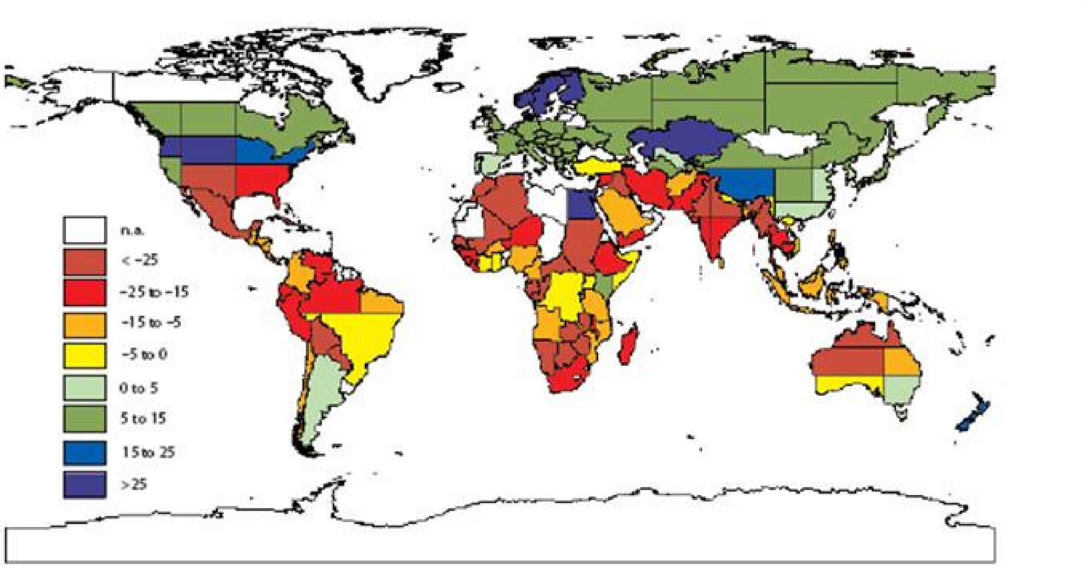

Figure 2. Impact on agricultural productivity with carbon fertilization (%)

Source: Cline (2007)

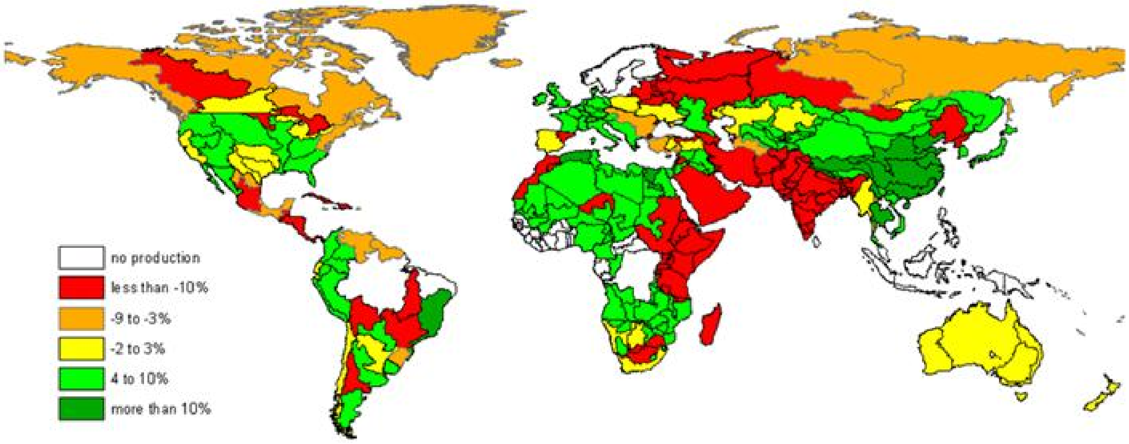

Figure 3. Projected percentage change of wheat yield in 2050 due to climate change

Source: IMPACT Projection 2008

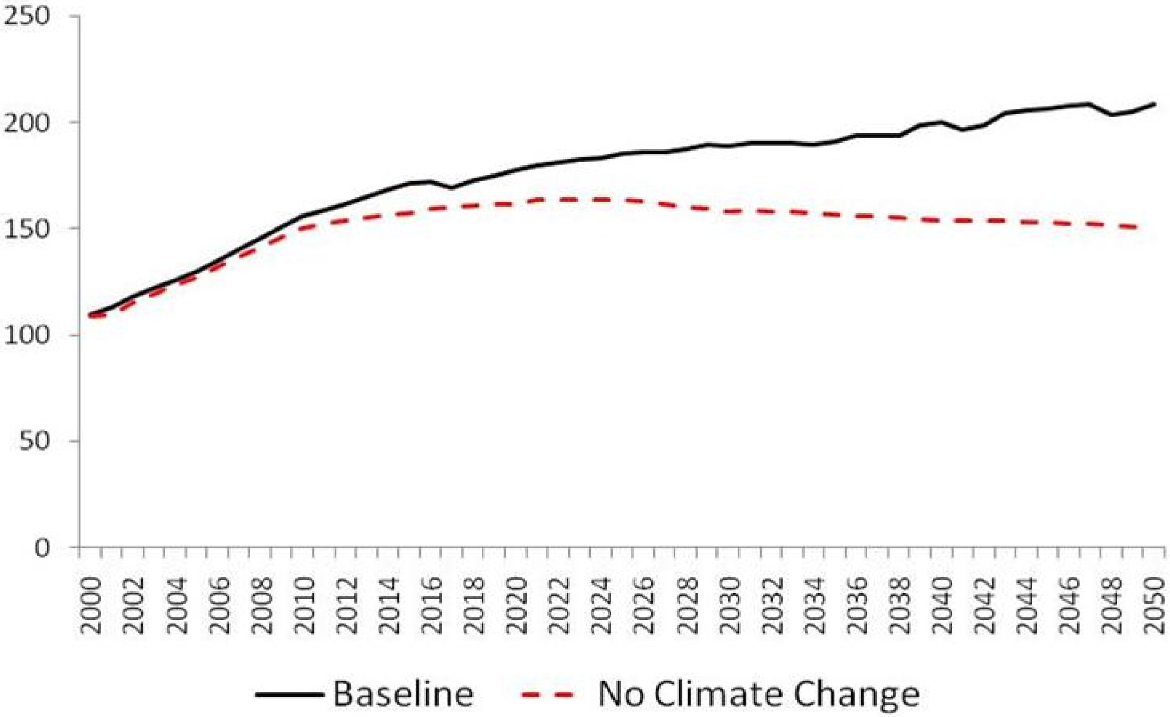

Figure 4. World prices of wheat under baseline and the scenario assuming no climate change

Source: IMPACT Projection 2008

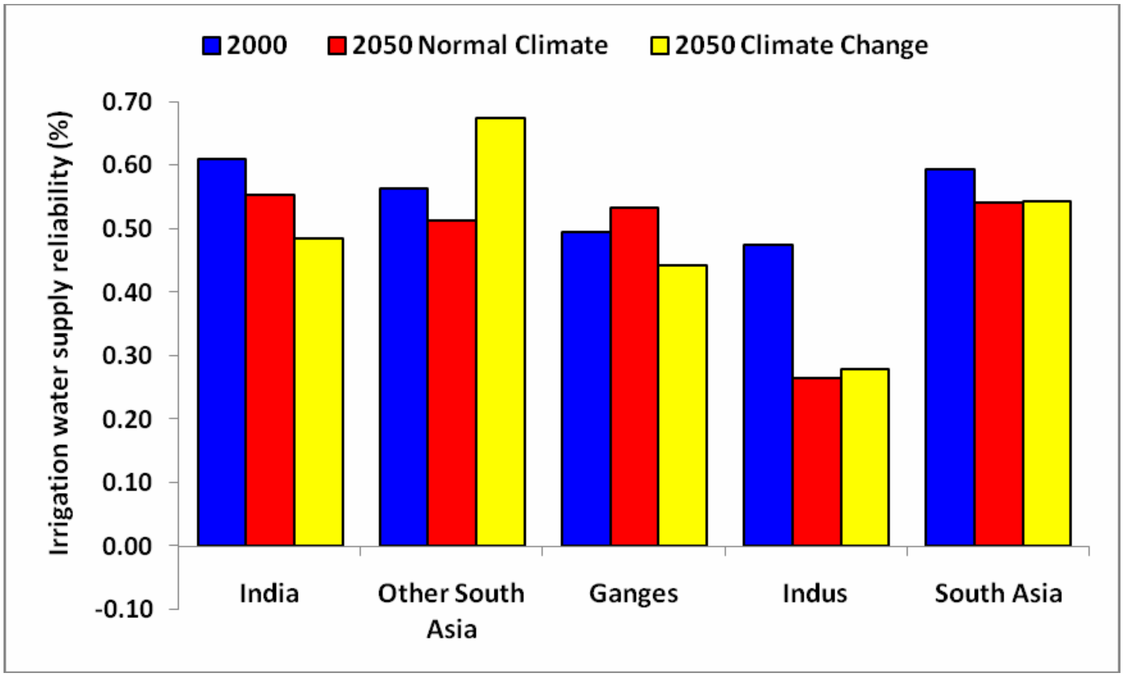

Figure 5. Irrigation water supply reliability (%) in selected areas of South Asia, 2000 and 2050

Source: IMPACT Projection 2008