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GLOBAL CLIMATE CHANGE AND ITS IMPACT ON AGRICULTURE

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Table of Contents

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1. Introduction

Climate is a primary determinant of agricultural productivity. In turn, food and fiber production is essential for sustaining and enhancing human welfare. Hence, agriculture has been a major concern in the discussions on climate change. In fact, the United Nations Framework Convention on Climate Change (UNFCCC) cites maintenance of our societal ability for food production in the face of climate change as one of the key motivations it's existence and for it's efforts in stabilizing greenhouse gas emissions (GHGE).

Food supply vulnerability to climate change is an issue in two different ways. First, future food supply may be directly threatened by climate change. Second, food supply capacity may be altered by efforts to reduce GHGE as society tries to mitigate future implications of climate change. This chapter reviews both sides of the issue summarizing economic considerations, concerns and research findings, building on the recent literature. In doing this the paper is broken into sections in with section 2 highlighting the longer run agricultural climate change issue. Section 3 treats the shorter run role of agriculture in mitigating GHGE. Section 4 presents concluding comments.

2. Agriculture and Climate Change

Agronomic and economic impacts from climate change depend primarily on two factors:

(1) the rate and magnitude of change in climate attributes and the agricultural effects of these changes, and
(2) the ability of agricultural production to adapt to changing environmental conditions.

2.1 Climate Change Effects on Agricultural Productivity

Temperature, precipitation, atmospheric carbon dioxide content, the incidence of extreme events and sea level rise are the main climate change related drivers which impact agricultural production. The main agricultural productivity implications of these drivers are indicated in Table 1. Briefly the main categories of agricultural productivity implications are

Crops and forage productivity and production cost where temperature, precipitation, atmospheric carbon dioxide content and extreme events are likely to alter plant growth and harvestable or grazable yield through a mixture of climatic and CO2 fertilization effects as well as impacts on plant water demand (through temperature affects on respiration and evapo-transpiration as well as CO2 affects on water use efficiency). Extreme events also play a role. For example where droughts and floods become more severe or frequent, agricultural losses would increase. For a more extensive discussion of these issues see Adams et al (1998).

Soil suitability for agricultural production which is affected in terms of available soil moisture for plant growth, moisture storage capacity and fertility. In particular, soil moisture loss is determined by temperature and maintenance of a constant water supply given any temperature increases need to be offset by precipitation increases and/or expansions in applied irrigation water. Furthermore, microbial decomposition is stimulated by warmer temperatures so the availability of soil nutrients and organic matter which helps hold the soil moisture may be negatively affected by warmer temperatures.

Livestock productivity and production cost which are affected both directly and indirectly. Direct effects involve consequences for the balance between heat dissipation and heat production. In turn according to Hahn (1995,2000) a change in this balance can alter: a) animal mortality, b) feed conversion rates, c) rates of gain, d) milk production, and e) conception rates. Appetite may also be affected (Adams et al (1998)). Finally, carrying capacity in a region is altered by changes in the availability of feed and fodder.

Irrigation water supply will be influenced by changes in the volume of water supplied by precipitation as well as by temperature alterations effects on evaporation. Also changes in temperature regimes can alter the timing of snow melt based runoff and thus both the seasonality of available water supply and the needed size of impoundments holding water for summer supplies. Groundwater recharge rates and aquifer exploitation may also be altered. Nonagricultural water demand by municipalities and possibly some industries is also likely to be increased by increases in temperature. Extreme events also play a role where, for example, some studies indicate that the hydrologic cycle will be intensified such that droughts and floods will become more severe in low- to mid-latitude regions again altering water availability seasonally and the need for impoundments (McCarl and Reilly(1999) and Jacobs, Adams and Gleick (2000) discuss these issues at more length).

Other Effects. In addition to the direct effects of climate change on agriculture, there are important indirect effects that can affect production. For example, sea level rise can inundate or require mitigation efforts along low-lying coastal regions. Indirect effects may also arise from alterations in the growth rates and distribution of weeds, pests and pathogens, rates of soil erosion and degradation, and alterations in ozone levels or UV-B radiation.

2.1.1 Adaptation

The consequences of climate change-induced agricultural productivity impacts will be, in great part, determined by human adaptations. Societies have adapted agriculture to a wide variety of climates around the world and the predicted rise in temperatures is less than the variability exhibited between regional climates. Thus adaptations to climate changes of the size forecast are already in existence in other parts of the world. Farm level cropping adaptations can be made in planting and harvest dates, crop rotations, crop mix, crop varieties, irrigation, fertilization, and tillage practices. Livestock producers can adapt to climate change by the provision of shading, sprinklers, improved air flow, lessened crowding, altered diets, and more care in handling animals. Herds or the locus of livestock production may also be moved to more hospitable locations. In the longer term, new crop varieties and livestock breeds may be developed that perform better under the anticipated future climate regime. Given these options, the IPCC (1996) report concluded that intensively managed livestock systems are potentially more adaptable to climate change than crop systems, particularly because they are better able to adapt to extreme events. Overall, adaptation can lessen the yield losses that might result from climate change, or improve yields where climate change is beneficial.

2.1.2 General Findings on Climate Change Impact

Several key findings have emerged across the large number of studies measuring the physiological effects of climate change on crops and to a lesser extent livestock.

1. The effects of changes in temperature, precipitation and carbon dioxide concentrations on crop productivity have been studied extensively using crop simulation models. The combined effects of climate change have been found to have implications for dryland and irrigated crop yields as well as irrigation water use. Table 2 presents a sample of worldwide crop yields implications drawn from Rosenzweig and Iglesias(1994) and IPCC(1996) while Table 3 presents a summary of the yield impacts found in the recent US National Assessment (Reilly et al, 2000a,b).

2. The effect on production is expected to vary by crop, and location as well as the magnitude of warming, the direction and magnitude of precipitation change. (See the reviews of this evidence in Adams et al(1998) and Lewandrowski and Schimmelfennig 1999).

3. Different crops exhibit different sensitivity. It is thus important that the full range of cropping possibilities is considered when assessing climate change. Treatment of only selected crops can bias the results. For example, early US studies only examined corn, soybeans and wheat, in contrast to later studies which included many more heat tolerant crops. The economic implications were moderated as a result. For an example of such an effect, see the experiment on cotton in McCarl(1999) which showed that explicit inclusion of the differential response by this more heat tolerant crop caused a reversal in sign of the total welfare impact showing a beneficial effect rather than detrimental effect of climate change.

4. The CO_2 fertilization effect is an important factor. Inclusion of the effect in yield studies significantly raises the estimates of climate effected yields of many crops. It is however somewhat controversial (see the discussion in the Reilly et al (2000b) or the CAST (1992 ,2001) reports)

5. Yield effects vary latitudinally across the world. Yields generally improve in the higher

latitudes,. On the other hand there are estimates that there will be net reductions in crop yields in warmer, low latitude areas and semi-arid areas. (See the reviews of this evidence in Adams et al 1998 and Lewandrowski and Schimmelfennig 1999).

6. Yield changes can be reduced or enhanced by adaptations made by producers. Farmers may adapt by changing planting dates, substituting cultivars or crops, changing irrigation practices, and changing land allocations to crop production, pasture, and other uses. (See R.M. Adams et al. 1999 and Kaiser et al. 1993).

7. Livestock effects can be significant. The EPRI sponsored (R.M. Adams et al.,1999) and recent US national assessment (Reilly et al , 2000a,b) used livestock productivity alterations ranging from -1.5 to -5% changes in rate of gain and milk production coupled with proportional adjustments in feed and grazing requirements and reductions in input usage costs at a rate of 40% of the reduction in productivity. Adjustments were also made in pasture requirements and range productivity in accordance with the change in pasture yield.

8. Irrigation water availability is an issue. Data from the US National assessment water study (Jacobs, Adams and Gleick, 2000) were used in the parallel agricultural assessment (Reilly et al (2000a,b)) under the assumption that the same percentage change occurring in total water supply also occured in the agricultural water supply. There is also a need to develop estimates on how nonagricultural water use might change in the face of climate change(see the discussion in McCarl and Reilly(1999)).

2.2 Economic Implications

The physical effects of climate change do not tell the whole story. Changes in agricultural supply result from the combination of changes in yields and changes in crop acreage as well as livestock herd size and location, livestock diet alterations, human consumption alterations, international trade adjustments and many other factors. These alterations are influenced by total production and market prices. Commodities that decline in supply will rise in price, *ceteris paribus*. Higher prices reduce consumption levels and adversely affect consumer welfare. In some cases, the negative effects on consumers may be partially or totally offset by producer gains from higher prices, but in general, total welfare tends to decline when supply is reduced. In the long term, higher prices stimulate producers to seek ways to increase supply, resulting in new equilibrium levels of prices and quantities.

2.2.1 Economic Methodology

Estimation of the magnitude of economic effects and adjustments have been done using economic concepts and models. A number of economic approaches and models are found in existing economic assessments. A simple taxonomy of these methods is to classify them as either "structural" or "spatial analogue" approaches. The characteristics of each approach are described here.

2.2.1.1 Structural Approach

The structural approach generally uses models, often from several disciplines, to simulate effects, adaptations and economic consequences of climate change. The approach typically starts with field or individual plant level crop simulation models to construct simulations of crop yield changes, possibly after adaptation by crop and region. In addition, estimates of livestock sensitivity and irrigation water supply are developed from other models or experts. In turn, the estimated effects are incorporated in an economic, possibly agricultural sector, model which simulates changes in acreage, livestock numbers, livestock feeding, commodity supply, international trade and consequent changes in market clearing prices. The economic models simulate behavior which seeks to maximize farm income or in national cases, consumers' and producers' welfare. This approach has been applied at the state (Kaiser et al., 1993), regional (Easterling et al. 1993), and national levels (Adams et al., 1988, 1990, 1995, 1999, McCarl 1999, Reilly et al 2000b). A key assumption of this approach is that producers', consumers', livestock feeders' etc. adaptation would proceed as modeled and that the simulated climate effects are accurate. Darwin et al. (1995) has developed a variant to look at global issues combining a global computable general equilibrium (CGE) model with a geographic information system (GIS) model to analyze potential climate change impacts on US agriculture, taking into account both interactions with the nonagricultural sector and other global regions.

Such structural economic models reflect varying levels of farmer adaptation and adjustment. A challenge in implementing this structural approach is to identify and incorporate important adaptations which farmers might employ. Because these economic models also typically estimate changes in market conditions under climate change (market clearing prices), these changes can be translated into changes in aggregate well being of consumers and producers. Such calculations are needed in order to understand the distributional consequences of climate change (i.e., who gains and who loses).

2.2.1.2 Spatial Analogue Approach

Alternatively a spatial-analogue approach has been used to simulate climate change effects on agriculture based on observed differences in land values, agricultural production or other climate related costs. Spatial-analogue models assume that cooler regions will behave like the patterns observed in other regions currently with warmer climate conditions if they were subjected to a climate change induced shift. A key premise is that farming practices, crop varieties, and cropping practices of farmers in warmer regions are transferrable.

Spatial-analogue models use statistical methods to analyze changes in spatial patterns of production; largely assuming costless structural adjustment and adaptation. Mendelsohn, Nordhaus, and Shaw (1994), for example, use a statistical approach to analyze cross-sectional data on land values to estimate the effects of climate shifts on producers' net income which by theory should be capitalized into land values. Chen and McCarl (2001) use a similar approach to look at pesticide treatment costs and Chen, McCarl and Schimmelfennig (2000) use such an approach to look at the implications for crop variability. Such an approach avoids the needs to develop information on physical effects and economic adjustments.

The spatial analogue approach sidesteps the problems plaguing the structural approach of needing to accurately model yield and water use/ supply physical implications of climate change. Rather it assumes the crop and farmer responses to climate are already present in the observed data such that the biophysical and economic adjustments imposed by climate change have been made across the landscape or time (an assumption that can be confirmed today by examining differences in cropping patterns and other agricultural practices across different climate regimes). However, the approach cannot fully account for items which are expected to vary significantly from historic observation such as CO_2 concentrations, international production shifts and large price alterations.

2.2.2 Economic Impact Findings

A large number of the economic effects of climate change on agricultural studies have been done. R.M.Adams et al(1998), Lewandrowski and Schimmelfennig(1999) and Reilly et al (2000b) provide reviews. A number of general findings have emerged

1. Over the next century, regional increases and decreases associated with climate change as now foreseen are not expected to result in large changes in global food production or any large global economic disaster in total food production. This likely occurs because the projected range of climatic alteration is less that the range of temperatures now experienced across productive areas of global agriculture. (Adams et al (1998), Lewandrowski and Schimmelfennig (1999) and Reilly et al (2000b) elaborate)

2. Impacts on regional and local food supplies in some low latitude regions could amount to large changes in productive capacity and significant economic hardship. (Adams et al (1998), Lewandrowski and Schimmelfennig(1999) and Reilly et al (2000b) elaborate).

3. Climate induced productivity changes that are harmful for consumers are typically beneficial to producers. In several studies of US agriculture that include price effects, reductions in crop yields indicate that consumers' would pay higher prices and receive smaller quantities of agricultural goods, and would thereby suffer economic losses (e.g. R.M. Adams et al (1990,1999), McCarl(1999),Reilly et al(2000a,b)). However, because consumers' demand for most crops are relatively inelastic with respect to price, declines in supply result in even greater percentage increases in prices. Consequently, producers' are projected to gain on average from revenue increases.

4. Climate change can influence prices, total acreage and market signals. The importance of market-level changes is illustrated in the estimates reported by Adams et al. (1995). Using estimated wheat yield changes from Rosenzweig, Parry, and Fischer(1995) for the US (shown earlier in Table 1), Adams et al. (1995) estimated a net increase in US wheat supply of between 4% and 15% because of increased wheat acreage. The Adams et al. (1995) findings on increase in wheat acreage were stimulated by an overall rise in the price of wheat precipitated by falling yields. Market-level total supply increases or decreases changes induce behavioral responses that mitigate impacts projected by biophysical changes alone.

5. Climate change induced change in total welfare and productivity estimates were negative in earlier studies but have tended to become less so and even beneficial over time. This occurs because the yield losses have been reduced due in part to milder temperature and precipitation estimates emerging from the global circulation models and enchanced CO_2 fertilization effects. This also implies that a reversion to larger climate changes as predicted in the earlier studies would raise the estimates. This can be examined by comparing the results obtained with the same methodology in R.M. Adams et al (1990,1995,1999) and McCarl (1999).

6. Climate change is likely to shift the comparative advantage of agricultural production regions. Such shifts are likely to alter the places in which specific crops are grown, both within countries and internationally, altering patterns of trade in agricultural commodities among regions and countries. (See Reilly, Hohmann, and Kane(1994) or Darwin et al(1995) for elaboration).

7. The economic consequences of yield changes will be influenced by adaptations made by farmers, consumers, government agencies, and other institutions. Farmers may adapt by changing planting dates, substituting cultivars or crops, changing irrigation practices, and changing land allocations among crop production, pasture, and other uses. Consumers may adapt by substituting relatively low priced products for those that become relatively high priced as a result of climate change effects. (See Adams et al (1998) or Kaiser et al (1993) for evidence and elaboration).

8. Welfare effects are sensitive to assumptions regarding CO_2 fertilization effect. For example, R.M. Adams et al. (1995, 1999) found positive increases in total economic welfare under CO_2 fertilizer effects but losses in the absence of these effects.

9. Pests are currently a major problem in US agriculture and climate change may exacerbate the problem. A spatial analogue study by Chen and McCarl (2001) shows pesticide use would be expected to increase for most crops in most states under the climate scenarios used in the recent U.S. National Assessment. This assessment approach did not consider increased crop losses due to pests, implicitly assuming that all additional losses were eliminated through increased pest control measures. Further in McCarl(1999) it was shown that this increase in pesticide use results in reduced overall national economic welfare. In addition, there could be substantial environmental consequences of increased pesticide use.

10. The consequences of climate change for US agriculture will be influenced by changes in climate variability and extreme events. A spatial analogue study by Chen, McCarl and Schimmelfennig (2000) shows projected climate change is likely to increase yield variability. One major source of weather variability is the El Niño Southern Oscillation (ENSO). ENSO effects vary widely across the country. Better prediction of these events would allow farmers to plan ahead, altering their choices of which crops to plant and when to plant them. The value of improved forecasts of ENSO events has been estimated

at approximately $500 million per year. As climate warms, ENSO is likely to be affected. Models project that El Niño events and their impacts on US weather are likely to be more intense (Timmermann et al(1999)). There is also a chance that La Niña events and their impacts will be stronger. Chen, McCarl and Adams(2001) studied this and found that changes in such events can impose significant costs on the agricultural sector.

11. Changes in climate are expected to affect the productivity and aggregate demand for factors of production such as water, labor, energy, and equipment. Climate change is analogous to technological change in agriculture, which can increase or decrease total factor productivity and can increase or decrease the productivity of one factor relative to another. Most studies for the US indicate that productivity changes triggered by climate change would generate changes in cultivated acreage by crop, total cultivated acreage, irrigation water consumption, farm employment and other changes in factor demands. The consequences of changes in factor demands on regional or local economies are largely unexplored but are potentially important.

3. Agriculture and Climate Change Mitigation

Regardless of the projected or actual impacts of climate change, agriculture is also likely to be directly or indirectly involved in climate change mitigation efforts. Greenhouse gas emissions (GHGE) constitute a global production externality which is likely to adversely affect climate. The UNFCCC is trying to negotiate net GHGE emission reductions. Actions under that convention yielded the Kyoto Protocol which represents the first significant international agreement towards GHGE reduction. Agriculture (using a definition including forestry) is mentioned as both an emitter and a sink in the protocol. Annex A lists agriculture as an emission sources from enteric fermentation, manure management, rice cultivation, soil management, field burning, and deforestation. The protocol also lists agriculturally related sinks of afforestation and reforestation. Additional sources and sinks are under consideration including agricultural soil carbon.

3.1 Ways Agriculture would be Affected by Climate Change Mitigation

Following the arguments in McCarl and Schneider (1999,2000a), there are at least four ways agriculture may participate in or be influenced by greenhouse gas mitigation efforts.

- Agriculture may need to reduce emissions because it releases substantial amounts of methane, nitrous oxide, and carbon dioxide.

- Agriculture may enhance its absorption of GHGE by creating or expanding sinks.

- Agriculture may provide products which substitute for GHGE intensive products displacing emissions.

- Agriculture may find itself operating in a world where commodity and input prices have been altered by GHGE related policies.

Each of these are discussed briefly in the following section

3.1.1 Agriculture - A source of greenhouse gases

The IPCC (1996) estimates that globally agriculture emits about 50% of total methane, 70% of nitrous oxide, and 20% of carbon dioxide. Sources of methane emissions include rice, ruminants and manure. Nitrous oxide emissions come from manure, legumes, and fertilizer use. Carbon dioxide emissions arise from fossil fuel usage, soil tillage, deforestation, biomass burning, and land degradation. Contributions across countries vary substantially, with the greatest differences between developing and developed countries. Deforestation and land degradation mainly occurs in developing countries. Agriculture in developed countries uses more energy, more intensive tillage systems, and more fertilizer, resulting in fossil-fuel based emissions, reductions in soil carbon, and emissions of nitrous oxides. In addition, animal herds emit high methane from ruminants and manure (IPCC (1996) and McCarl and Schneider (1999,2000a) elaborate).

3.1.2 Agriculture - A sink for greenhouse gases

The Kyoto Protocol allows credits for emission sinks through afforestation and reforestation. Provisions allow for consideration of additional sources and sinks. Agriculture can serve as an emission sink in mainly offsetting CO_2 emissions. Management practices can increase soil carbon retention (commonly called carbon sequestration). Such practices include land retirement (conversion to native vegetation), residue management, less-intensive tillage, land use conversion to pasture or forest, and restoration of degraded soils. While each of these can increase the carbon-holding potential of the soil, some issues are worth noting. Soils can only increase carbon sequestration up to a point. Retained carbon increases until it reaches a new equilibrium state that reflects the new management environment. As the soil carbon level increases, soil absorption of carbon decreases and soil potential to become a future *emission* source since subsequent alteration of the management regime can lead to carbon *releases*. Third, enhanced carbon management can reduce agricultural productivity. (IPCC 1996, 2000, Marland, McCarl and Schneider (1998) and McCarl and Schneider (1999,2000a) elaborate).

3.1.3 Agriculture - A way of offsetting net greenhouse gas emissions

Agriculture may provide substitute products which replace fossil fuel intensive products. One such product is biomass for fuel usage or production. Biomass can directly be used in fueling electrical power plants or maybe processed into liquid fuels. Burning biomass reduces net CO_2 emissions because the photosynthetic process of biomass growth removes about 95 percent of CO_2 emitted when burning the biomass. Fossil fuel use, on the other hand, releases 100 percent of the contained CO_2. Substitute building products can be drawn from forestry reducing fossil fuel intensive use of steel and concrete. (Marland and Schmalinger(1997) elaborate). Cotton and other fibers also substitute for petroleum based synthetics.

3.1.4 Agriculture - Operating under fuel taxes

The need to reduce emissions and the implementation of emissions trading will likely affect fossil fuel prices. For example, diesel fuel distributors might need to purchase an emissions permit, effectively raising fuel prices. Similarly, the US might implement some sort of fuel tax. The tax and corresponding transportation cost increases might influence the cost of petrol-based agricultural chemicals and fertilizers as well as on-farm fuel prices and off-farm commodity prices.(McCarl, Gowen and Yeats(1999), USDA(1999), Antle et al (1999), and Konyar and Howitt(2000) elaborate)

3.2 Economic Appraisal of Agricultural Effects of Climate Change Mitigation Actions

A number of climate change mitigation impact studies have been done although this is very much an emerging literature. McCarl and Schneider (1999,2000a) provide a review. Across that literature a number of general findings have emerged.

1. Agricultural emission reductions and offsets can be cost effective strategies for GHGE offsets at relatively lower carbon prices. McCarl and Schneider(2000a) amass substantial evidence for the aforementioned emission reductions and sequestration options. Recent studies by Pautsch et al (2000), Antle et al (2000) and McCarl and Schneider (2000b) show low cost potential for agricultural soil carbon sequestration. The literature cited by D.M. Adams et al(1999) as well as their numerical results show low cost potential in forest soils and standing timber.

2. Agriculture can operate in the face of carbon induced fuel price increases without great dislocation as shown in the studies by McCarl et al (1999), USDA(1999) and Antle et al (1999). Konyar and Howitt (2000) show greater sensitivity but use a $348 per ton carbon price. Francl (1997) shows large net income losses but used an analytic framework which embodied assumptions precluding adjustments in either market consumption behavior or production patterns.

3. Agricultural emission offsets are competitive with food production. For example McCarl and Schneider (2000b) find substantial decreases in food production and increases in food prices at higher carbon prices. Similarly, Konyar and Howitt(2000) show consumers' effects at high carbon price induced fuel taxes.

4. Agricultural soil and forestry based carbon sequestration can be competitive at low carbon prices. Thus, there is real potential that management and the allocation of land between forestry and agriculture may be affected by climate change mitigation efforts. However, while Lal et al (1998) and others provide large estimates for the potential of carbon sequestration based on land potential in both of these arenas, studies have shown that at lower carbon prices the realized sequestration acreage is substantially lower than the total estimated potential. (See D.M. Adams et al (1999), McCarl and Schneider(2000b), Babcock and Pautsch(1999) and Antle et al (2000) in contrast with Lal et al 1998 for evidence).

5. Across the array of potential agricultural emission reduction, substitution and offset alternatives, there are alternatives with substantially different economic potential. In

particular in the study by McCarl and Schneider(2000b) the replacement of power plant coal fired electricity generation with biofuels plays a substantial role but only at carbon prices above $60 per ton while at low prices agriculturally based soil carbon sequestration, afforestation and fertilization modifications dominate the set of "best" strategies. In that study methane and ethanol strategies exhibited low potential.

6. Mitigation activity stimulated by carbon price increases generally improves producers' welfare and decreases consumers' welfare (See the results in McCarl and Schneider(2000b), McCarl, Gowen and Yeats(1999), USDA(1999) and Konyar and Howitt(2000) for evidence).

7. The inclusiveness of the international scope of emissions trading regime influences the magnitude of the welfare effects in implementing countries. In particular Lee et al(2000) find producers' welfare in the US is greater with a broader trading regime than occurs under restricted trading in the US alone or the US and Kyoto Protocol annex I countries.

4. Concluding comments

Agriculture can be affected by future climate change and current or relatively near-term efforts to mitigate climate change. There is a growing literature on both of these topics and this paper has attempted to introduce the reader to a significant component of these bodies of literature. In terms of projected long term climate change, the global agricultural production system appears able to continue high productivity without global threat to food security although substantial regional disturbances can occur. In terms of climate change mitigation, there is vulnerability in terms of agricultural production with mitigation efforts competing with traditional agricultural food production. Climate change mitigation effects may largely benefit producers at the expense of consumers and help support agricultural producer incomes.

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Table 1. Types of impacts on agricultural production and markets

Item subject to impact	Type of Effect				
	Temperature	Precipitation	CO2	Extreme Events	Sea Level
Crops and Forages					
Plant Size - yield	X	X	X	X	
Water requirement	X		X		
Soils					
Soil Moisture	X	X		X	
Soil fertility	X	X			
Livestock					
Rate of gain	X			X	
Feed use	X			X	
Milk production	X			X	
Fertility	X			X	
Carrying Capacity	X	X	X	X	
Irrigation water supply					
Quantity	X	X		X	
Seasonality of supply	X				
Non agricultural competition	X	X		X	
Other					
Navigation		X		X	X
Low lying land innundation				X	X
Weed Competitiion	X	X	X		
Insects, fungus, diseases	X	X			

Table 2. Range of Estimated Effects on Country Crop Yields as Assembled by Rosenzweig and Iglesias(1994) and IPCC(1996)

Location	Impact (Crop: % Change in Yield)
Indonesia	Rice: -2.5% and +5.4%; Soybeans: -2.3%; Maize: -40%
Malaysia	Rice: -22% to -12%; Maize: no change; Rubber:-30% to -3%
Pakistan	Wheat -60% to -10%
Sri Lanka	Rice: -2.1% to + 3%
Bangladesh	Rice: -6% to +8%
Mongolia	Spring wheat: -74.3% to +32.0%
Kazakhstan	Spring wheat: -56% to -44% Winter wheat: -35% to +15%
Czech Republic	Winter wheat: -3% to +16%
United Kingdom	Crop productivity (+5% to +15%)
The Gambia	Maize: -26% to -15%, Early millet: -44% to -29% , Late millet: -21% to -14% Groundnuts: +40% to +52%
Zimbabwe	Maize: -13.6% to -11.5%
Brazil	Maize: -27% to -7% Wheat: -46% to -17%, Soybeans: -6% to +38%
Argentina	Maize: -17 to +4, Wheat: -12% to +6%
Uruguay	Barley: -40%, Wheat: -31% to -11%
United States	Wheat: -14% to -2%, Maize: -29% to -15%, Rice: -23% to +1%

Table 3. National Average Data on 2030 Irrigated and Dryland Crop Yield and Irrigation Water Use Sensitivity to Global Climate Change Estimates as Developed in the US Global Climate Change Research Program National Assessment for Year 2030

	------------------------ Without Adaptation --------------------			----------------------- With Adaptation -------------------------		
Crop	Dryland Yield	Irrigated Yield	Irrigation Wat Use	Dryland Yield	Irrigated Yield	Irrigation Wat Use
Cotton	+18% to +32%	+36% to +56%	-11% to +36%	na	na	na
Corn	+11 to +19%	-1% to +21%	-30% to +57%	+11 to +20%	+1% to +21%	-32% to +57%
Soybeans	+7% to +34%	+16% to +17%	-12% to 0%	+7% to +49%	+23%	0% to +18%
Hard Red Spr Wheat	+15% to +20%	-10% to +4%	-28% to -17%	+17% to +23%	-6% to +10%	-12%
Hard Red Win Wheat	-16% to +24%	-4% to +5%	-8% to +5%	-9% to +24%	-1% to +8%	-6% to +9%
Soft Wheat	-5% to +58%	-6% to +3%	-12% to +5%	-3% to +58%	-5% to +5%	-26% to +3%
Durham Wheat	+10% to +21%	-10% to +5%	-25% to +15%	+10% to +22%	+2% to +9%	-10% to -5%
Sorghum	+15% to +17%	-1% to +1%	-9% to -7%	+32% to +43%	+22% to +22%	+2% to +3%
Rice	na	-2% to +9%	-10% to -2%	na	+7% to +9%	+2% to +5%
Potatoes	+6% to +7%	-6% to -3%	-5% to -1%	+7% to +8%	-4% to -1%	-3% to 0%
Tomatoes	na	-9% to +1%	-9% to -5%	na	+1% to +10%	-8% to +2%
Citrus	na	+32% to +40%	-21% to -6%	na	na	na
Hay	-10% to +43%	+3% to +37%	-29% to +44%	na	na	na
Pasture	+3% to +22%	na	na	na	na	na

Notes: **na** in the table indicates results were not developed for this case due to the small acreage involve (usually in the dryland or irrigated cases) or that the simulation was not done (in the adaptation cases as only selected crops were studied)

The data give percentage change in the item from a no climate change case.

Source: Drawn from Chapter 3 of Reilly et al(2000b).