Chapter 6: Climate Change and Texas Agriculture

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Productivity and income in agriculture is heavily influenced by climatic conditions. Changes in temperature, precipitation, extreme events, water flows and atmospheric content has a mixture of positive and negative implications for plant growth, livestock performance and water supply, as well as for soil characteristics, pests and diseases. Thus, this industry is likely to face changing conditions and may be at risk given the possible incidence of global climate change. This chapter examines the vulnerability of agriculture in Texas to global climate change.

Estimation of the effects of climatic change on agriculture is difficult. Basically there are three methods that could be used to make such an estimate. The first is based on observation, but this would entail waiting for climate change conditions to fully occur, either globally or in representative regions. This is not now possible for the combination of CO_2 and climatic effects that we expect in the future. Second, one could turn to experimentation where agricultural production systems are subjected to climatic change scenarios and the production implications observed. This, however, is also not feasible as the sites and systems to be investigated would render such an undertaking quite expensive. In addition, even if completed, the results would not tell the effects on crop mix, markets, international trade, livestock herd size, etc. Thus we turn to a third, simulation-based approach where models are used to simulate crop yields, crop mix choice and market processes. This approach requires the adoption of scenarios regarding both climate effects and agricultural production/consumption conditions. It also necessitates the use of agricultural scenarios that are available, because the resources supporting this work do not permit reruns of the crop and hydrological simulations that are input to this work. Thus the climate and associated agricultural and hydrological scenarios adopted are those resulting from the US National Assessment (Reilly et al 2001, 2002a, b).

The first part of the chapter discusses how global climate change might influence agricultural processes. Second, results are presented from an assessment of the influence of climate change on crop yields and the agricultural economy under 2007 conditions[1]. Third we focus in on a regional study in the area around San Antonio where we examine agricultural effects in the face of nonagricultural and ecological competition.

FACTORS DETERMINING THE SENSITIVITY OF AGRICULTURE

Agricultural production is influenced in numerous ways by the forces causing climate change, as well as the altered climate attributes. Drivers that lead to effects on agriculture will be grouped into five categories:

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[1] The 2007 base was used as opposed to a future year as prior experience has shown that the model variation introduced by making assumptions about future technological progress, demand, exports etc. is far larger than the implications of most phenomena such as climate change.

- Temperature affects plants, animals, pests and water supplies. For example, temperature alterations directly affect crop growth rates, livestock performance and appetite, pest incidence and water supplies in soil and reservoirs among other influences.
- Precipitation alters the water directly available to crops, the drought-stress crops are placed under, the supply of forage for animals, animal production conditions, irrigation water supplies, and river flows supporting barge transport, among other items.
- Changes in atmospheric CO_2 influences the growth of plants by altering the basic fuel for photosynthesis, as well as the water that plants need as they grow, along with the growth rates of weeds.
- Extreme events influence production conditions; water supplies and can alter waterborne transport and ports.
- Sea level rise influences ports, waterborne transport and can inundate producing lands.

Reasons for such vulnerability and the manifestations of it are discussed in many places, including Adams et al (1989, 1990, 1999), Reilly et al (2002a) and the Intergovernmental Panel on Climate Change Reports (IPCC 2001, 2007).

NATIONAL AND TEXAS ANALYSIS

The climatic conditions projected for the future do not exist in today's world, and thus the full implications of such changes cannot be fully evaluated. Some studies have examined differences in agricultural production patterns across regions with varying climates, using these differences to infer how shifts in climate would lead to shifts in production patterns. If, for example, the climate of Michigan became like that of Indiana, or North Dakota like that of South Dakota, then perhaps agriculture would shift in these Northern states to be more like that of more Southern states. One of the major limitations of this procedure is that one cannot observe the consequences of an enriched CO_2 atmosphere, which will also have substantial effects on plant performance. Moreover, studies using such a procedure have not investigated effects of changing commodity prices and of international trade.

The approach used here is to employ process models of crop and livestock response to weather and changing CO_2 concentrations, and use these to simulate a market model of the agricultural economy. The process models can take advantage of the experimental evidence of crop response to changing CO_2, and the market model can simulate price and trade effects of changing production. In doing this we follow a number of previous studies and use a multi-step analytical process. Namely:

- Projections about future atmospheric greenhouse gas (GHG) emissions and concentrations are taken from existing studies.
- Climatologists use global circulation models (GCMs) to simulate future climatic conditions for the world, resolved at a latitude-longitude grid level, typically on the order of 2° x 2° (roughly 125 mile square areas).
- Agricultural and hydrological scientists employ crop, livestock, water flow and other simulators to examine sensitivity as it varies geographically, scaling the climate projections from the GCM down to sites where detailed information needed to run the models is available. The simulators take into account water available, soil characteristics and other factors. They are typically simulated under conditions where

fertilizer, water applied in areas with irrigation, planting dates, and other management variables are left unchanged (no adaptation), and under conditions where levels of management variables are changed (with adaptation) to either increase yields further or to reduce yield losses.

- Economists use agriculture sector models to evaluate how multiple production changes, as they differ across the US and world, come together to affect markets, and how farmers in turn respond. The results of the economic modeling show how total crop and livestock production is affected. Items of interest include shifts in the geographic incidence of crop acreage and livestock numbers, along with the effects on many performance measures including markets, prices, incomes and environmental factors. Such economic models include further adaptations farmers would make in response to changing economic conditions. This would include changing the type of crop or livestock produced, abandoning or adding irrigation, or switching land into or out of crop production altogether.

This broad methodology will be employed herein. However, we will only utilize results from other studies for the first three stages regarding atmospheric GHG scenarios, GCM based climatic projections and simulations of water, agricultural crop and livestock performance. The new work done here involves the economic sector analysis. For water, crop and livestock performance simulation data we rely largely on the coordinated efforts that were done under the agricultural component of the US Global Climatic Change Research Program (USGCRP) US national level assessment (Reilly et al 2001, 2002 a, b). The climate scenarios used are:

- Hadley – a climate change scenario developed by the United Kingdom Hadley Climate Center as used in the USGCRP National Assessment where, according to the Agriculture Report (Reilly et al 2002 a), "For the continental United States, the Hadley scenario projects a 1.4º C (2030) and 3.3º C (2095) increase in temperature with precipitation increases of 6 and 23 percent, respectively. . ., more warming in the winter and relatively less in the summer. The mountain states and Great Plains are also projected to experience more warming than other regions… shows greater warming in the Northwest."
- Canadian -- a climate change scenario developed by the Canadian Climate Center as also used in the USGCRP National Assessment where, according to the Agriculture Report (Reilly et al 2002 a), "For the continental United States, the Canadian model scenario projects a 2.1º C average temperature change with a 4 percent decline in precipitation by 2030 and a 5.8º C warming with a 17 percent increase in precipitation by 2095 . . . more warming in the winter and relatively less in the summer. The mountain states and Great Plains are also projected to experience more warming than other regions.

Agricultural Sensitivity

A number of elements of agricultural production were shifted in the face of climate change. These and the procedures used are explained in McCarl and Reilly (2007) and were:

- Crop yields were altered under climate change based on the estimates from various crop simulators, as discussed in the US agricultural sector appraisal (Reilly et al 2002a). Table 6.1 shows the data generated for Texas regions for the cotton, corn and sorghum crops. It is evident that the different climate change scenarios have implications for crop yields. Generally, excepting for cotton, the Texas yield changes were lower or more negative than in the rest of country.

Table 6.1: Percent changes in crop yields by Texas and US region

	Hadley Climate GCM			Canadian GCM		
	Cotton	Corn	Sorghum	Cotton	Corn	Sorghum
TxHiPlains	101	-3	22	78	-14	43
TxRollingPl	46	9	24	26	0	53
TxCntBlack	36	11	24	21	2	54
TxEast	12	9	23	9	1	51
TxEdplat	35	-2	23	21	-12	48
TxCoastBe	11	11	24	6	3	55
TxSouth	20	6	23	13	-3	47
TxTranspec	9	-4	17	7	-15	13
CornBelt	13	12	36	8	12	34
GreatPlains	13	9	30	8	6	25
LakeStates	0	47	0	0	62	0
NorthEast	0	5	33	0	0	28
RockyM	31	4	87	26	-2	52
PacificSW	-6	-3	107	-5	-7	53
PacificNW	0	-3	0	0	-7	0
SouthCen	20	7	30	13	-5	26
SouthEast	21	4	29	12	-8	25
SouthWest	69	4	26	50	-5	43
US Average	34	16	31	24	16	33

Levels of inputs such as fertilizer, energy, labor and insecticides were varied with crop production changes. For example, if yields are higher more inputs are needed, whereas if yields are lower then less are needed. Farm level evidence suggests that the change in input use is less than proportional to the yield change. The estimated relationships vary by crop, but the change for most crops was on the order of a 0.4 percent change in input use for a 1.0 percent change in yield.

- Nationally water demand by irrigated crops dropped substantially for most crops, but it increased in Texas.
- Climate change can have implications for livestock, principally through changes in appetite and the distribution of energy between maintenance and growth. Disease incidence is also likely to be affected. The result is altered milk and meat production,

meat quality and species reproduction as climate changes. A study conducted under sponsorship by the Electric Power Research Institute (Adams et al. 1999) developed relationships between temperature change, livestock performance and feedstuff consumption in consultation with experts on livestock production and management. The results generally show a reduction of 5-7 percent in annual per animal production of meat, milk and wool.

- The amount of feedstuffs and other inputs change when livestock productivity changes. We assume that feedstuff use is strictly proportional to the volume of animal products produced. The use of the non-feed inputs changed by 0.5 percent for every 1.0 percent change in livestock yields.
- Climate change can affect water supply and in turn the amount of irrigation water available for agriculture in several different ways. The national assessment water study (Gleick et al 2000) developed a set of climate effects on surface water availability. These data show that the Pacific Southwest gains the most (this might be modified under the latest climate scenarios since that region is dryer than in the GCM runs used here) under the climate change scenarios with the smallest gains/largest losses generally being in the southern regions including Texas. Note that the Canadian scenario is the most extreme, while the Hadley is the most optimistic.
- Climate change will affect grass growth and thus the effective supply of pasture and animals that can be supported on Western grazing lands. We assumed that climate change altered livestock usage of grazing lands in proportion to the effect of climate change on animal performance. We also assumed altered rates of grass growth due to changing climate effectively changed grazing land availability using the hay crop simulation results.
- Evidence suggests that problems involving pests (herein defined as insects, weeds and diseases) are greater in warmer areas. Thus, climate change may lead to changes in the range/incidence of agriculturally damaging pests. To consider how climate could affect agriculture, we used the approach measuring pest damages as a change in expenditures on pest control that was developed in the US National Assessment (Chen, Gillig and McCarl 2001). The results show an increase in crop expenditures for almost all crops under all scenarios. The largest increases are found for corn and potatoes, with smaller increases for cotton and the wheat crops.

Economic Analysis

The agricultural sector scenario involves assumption of the 2007 status quo, as projection of future rates of technological progress and consumption growth is both difficult and potentially a much larger factor than climate change itself, thereby swamping the climate change effects. As such then, the year 2007 is used throughout.

A total of three economic model runs were performed: a base case without climate change and a case for each climate change scenario. The overall societal welfare results of this analysis are shown in Table 6.2. These results show total societal welfare increases about $29 billion under the Hadley scenario and about $22 billion under the Canadian scenario. In addition, producers benefit under both scenarios, obtaining most of the gain, whereas consumer welfare shows smaller but positive gains. Foreign welfare shows gains, but with losses to foreign producers. These results suggest that the national agricultural sensitivity to global climate change is small. The growth stimulating effects of CO_2, coupled with cropping pattern substitution, overcomes the negative effects regarding water supply and, in some cases, yield.

Table 6.2: National and global welfare results under climate change

		Climate Scenario	
	Base	Canadian	Hadley
		Change from the Base	
United States			
US Consumers	1781612	1772	9799
US Processors	3249	282	121
US Producers	66911	18143	16548
Total	1851772	20195	26468
Rest of the World			
Foreign Consumers	289973	3782	4741
Foreign Producers	20806	-991	-1805
Total	310780	2792	2936
Total Globally	2162552	22988	29404

When model projections regarding commodity prices and production are reviewed, price decreases are observed across almost all commodities, and these price decreases are matched by increased production levels.

Table 6.3 provides selected results for Texas. In Texas more cotton and sorghum is projected, while production of wheat, corn, rice, cattle and broilers falls. Cropped acres are reduced by about 20 percent, and irrigation water use falls largely due to less water available.

EDWARDS AQUIFER REGIONAL ANALYSIS

A very important issue regarding climate change and Texas agriculture involves the tradeoffs between agricultural, municipal, industrial and environmental uses for water. To explore such issues, I review the results of a study done by Chen, Gillig and McCarl (2001) regarding the San Antonio Texas Edwards Aquifer. In particular, that paper explored the implications of recent climate change projections for the San Antonio Texas Edwards Aquifer (EA) region, concentrating on changes in intersectoral water use patterns, environmental matters and the economy.

There are many competing uses for EA waters including municipal, agricultural, industrial, military and recreational. The EA also discharges water to artesian Springs in the eastern part of the aquifer. Pumping in the western part of the EA is largely by agricultural users (AG), whereas eastern pumping is mainly by municipal and industrial water users (M&I). Spring discharge, mainly from San Marcos and Comal springs in the East, supports a habitat for endangered species (Longley 1992), provides water for recreational use, and serves as an important supply source for water users in the Guadalupe-Blanco river system. The EA has substantial recharge, which between 1934 and 1996 averaged 658,200 acre feet (af). Over that period, pumping and springflow discharge averaged 668,700 af (US Geological Survey - USGS, 1997). Use has increased in the past, with pumping rising by 1 percent a year in the 1970's and 1980's (Collinge et al. 1993) and, as of 2001, accounted for 70 percent of the total discharge. The increasing use placed the aquifer under stress, leading to increased annual variability, lessened springflow and increased concern over the endangered species habitat. This stress and other factors led to a successful lawsuit by the Sierra Club to protect the endangered species (Bunton 1996) and to the Aquifer being placed under pumping limitations by the Texas Legislature (Texas Senate 1993), although these were increased in 2007.

Climate change could increase the stress on the EA, altering recharge and increasing water demand. This study utilizes an existing EA hydrological and economic systems model – EDSIM (McCarl et al. 1998), coupled with an examination of climate change implications for recharge and water demand.

Table 6.3: Selected Texas results under climate change

	Base	Canadian	Hadley
Producer Net Income ($million)	4757	4707	4253
Index Numbers			
Production			
All Farm Prod	100.00	90.78	96.54
All Crops	100.00	90.70	96.46
All Livestock	100.00	90.15	96.00
Price			
All Farm Prod	100.00	101.61	93.12
All Crops	100.00	92.85	91.10
All Livestock	100.00	107.13	94.56
Calves in feedlots	8095	7000	771
Total Broilers	596066	488384	542917
Acres cropped	1267426	985952	984254
Irrigation water use	5831	5885	5500

Climatic Change Recharge and Water Demand

The results from US National Assessment scenarios were used to provide the climate change scenarios. The average changes in regional temperature and precipitation for 10 year periods centered on 2030 and 2090 are given in Table 6.4. Such changes would alter water demand and supply. We examine implications for EA recharge, crop and municipal water demand, plus agricultural yields.

Table 6.4: Changes in EA Region Temperature and Precipitation by Scenario

Climate Change Scenario	Temperature (^{0}F)	Precipitation (Inches)
HADLEY 2030	3.20	-4.10
HADLEY 2090	9.01	-0.78
CANADIAN 2030	5.41	-14.36
CANADIAN 2090	14.61	-4.56

Recharge Implications

Chen, Gillig and McCarl used a regression analysis to estimate the effects of climate change on recharge in the form of changes in temperature and precipitation. In particular, USGS (1997) estimates of historical recharge data by county during 1950 to 1996 were drawn from the Edwards Aquifer Authority annual reports, while associated climate data were obtained from the Office of the Texas State Climatologist and a University of Utah web page.

Monthly recharge was forecast as a loglinear function of temperature and precipitation, as explained in Chen, Gillig and McCarl. Their summary measures for recharge implications are displayed in the top of Table 6.5 and show recharge reductions ranging from 20.59 to 48.86 percent.

Municipal Water Use Implications

Chen, Gillig and McCarl relied on estimates from Griffin and Chang (1991) to estimate how municipal water demand would be affected. They adjusted the daily climate record from 1950 to 1996, altering the temperature and precipitation so that it reflected the differences in the climate change scenarios. The results show that climate change would increase municipal water demand by 1.5-3.5 percent.

Crop Yields and Irrigation Water Use

Climatic change would also influence crop yields and irrigation crop water requirements. Chen, Gillig and McCarl estimated this using the Blaney-Criddle (BC) procedure (Heimes and Luckey 1983; Doorenbos and Pruitt 1977). Some of their summary measures of the resultant effects are also presented in Table 6.5. Those measures show a decrease in yields and an increase in water requirements.

Table 6.5. Selected Effects of Scenarios on EA Regional Items

		Hadley-2030	Hadley-2090	Canadian-2030	Canadian-2090
		-- Percent Change from without climate change case --			
Aquifer Recharge	Recharge in drought years	-20.59	-32.89	-29.65	-31.96
	Recharge in normal years	-19.68	-33.46	-28.99	-36.23
	Recharge in wet years	-23.64	-41.45	-34.42	-48.86
Municipal Water demand		1.539	2.521	1.914	3.468
Crop Yields and Water Use	Irrigated Corn Yield	-1.93	-3.47	-4.26	-5.61
	Irrigated Corn Water Use	11.95	31.32	23.47	54.03
	Dryland Corn Yield	-3.93	-6.78	-8.17	-10.79
	Irrigated Sorghum Yield	-1.75	-3.35	-2.79	-4.17
	Irrigated Sorghum Water Use	15.12	38.16	42.65	79.36
	Dryland Sorghum Yield	-5.93	-13.07	-10.82	-16.76
	Irrigated Cotton Yield	-9.06	-15.82	-19.80	-24.64
	Irrigated Cotton Water Use	16.88	40.82	34.58	71.50

Economic Damages

The climate-induced changes estimated above were factored into a regional EA region economic and hydrological simulation model- EDSIM as developed by Dillon (1991); McCarl et al. (1993); Lacewell and McCarl (1995); Keplinger and McCarl (1995); Keplinger (1996); Williams (1996) and McCarl et al. (1998). EDSIM depicts pumping use by the agricultural, municipal and industrial sectors, while simultaneously calculating pumping lift, ending elevation and springflow. EDSIM simulates regional municipal, industrial and agricultural water use, irrigated versus dryland production and choice of irrigation delivery system (sprinkler or furrow) across a nine-state representation of the probability distribution of precipitation, EA recharge and crop water demand/yield. The model computes regional welfare, which is the sum of net farm income and municipal and industrial (M&I) consumers' surplus. Total water usage is constrained to be less than or equal to the 400,000 af pumping limit, as mandated by the Texas Senate for years after 2008.

Five scenarios were considered by Chen, Gillig, and McCarl: 1) BASE without climate change; 2) climate change as predicted by the Hadley GCM for 2030; 3) climate change ala the Canadian GCM for 2030; 4) climate change ala HADLEY for 2090; and 5) climate change ala CANADIAN for 2090. The results appear in Table 6.6.

Table 6.6. Aquifer Regional Results under Alternative Climate Change Scenarios

			Climate Scenario			
Variable	Units	Base	Hadley-2030	Hadley-2090	Canadian-2030	Canadian-2090
			------------ Percent change from Base Scenario ------------			
Ag Water Use [a]	1000 af	150.05	-0.89	-2.4	-1.35	-4.15
M&I Water Use [b]	1000 af	249.72	0.63	1.54	0.9	2.59
Total Water Use	1000 af	399.77	0.06	0.06	0.06	0.06
Net AG Income [c]	1000 $	11391	-15.85	-30.34	-29.41	-44.97
Net M&I Surplus [d]	1000 $	337657	-0.2	-0.58	-0.36	-0.92
Authority Surplus [e]	1000 $	6644	3.76	12.73	7.07	21.6
Net Total Welfare	1000 $	355692	-0.64	-1.3	-1.16	-1.93
Comal Flow [f]	1000 af	379.5	-9.95	-20.15	-16.62	-24.15
San Marcos Flow [g]	1000 af	92.8	-5.07	-10.09	-8.3	-12.06

Source: Chen Gillig and McCarl (2001)

Notes

a	Total agricultural water use.
b	Total municipal and industrial water use.
c	Net farm income.
d	Net municipal and industrial surplus.
e	Welfare accruing to the pumping or springflow limit -- the rental value of all permits
f	Total annual flow at Comal springs
g	Total annual flow at San Marcos springs.

In those results the strongest effect of climate change falls on springflow and the agricultural sector. Springflows at Comal (the most sensitive spring) decrease by 10-16 percent under the 2030 scenarios and 20-24 percent under 2090. Farm income falls 16-30 percent under the 2030 scenarios and 30-45 percent under 2090. The shift in agricultural water use to M&I water use indicates that the city users will buy out some agricultural usage through water markets.

Despite an increase in M&I water use, the M&I surplus decreases. This is because of an increase in pumping lift and cost due to lower recharge and falling EA levels. The value of water use permits increases by 5-24 percent. Water use in the nonagricultural sector is less variable and a shift to that sector actually makes water use slightly greater, with corresponding declines in springflow.

The reduction in springflow would put the endangered species habitat in additional peril. Thus a reduction in the allowed pumping may be required to protect the springs, endangered species and other environmental amenities. Additional simulations show that, to maintain the springflow level, the EA pumping limit level needs to decrease by 9-20 percent at an additional cost of $0.5 to $2 million per year.

CONCLUSIONS

A quantitative examination of the agricultural effects of climate change was carried out in a nationwide context. Generally, the results show, much like in the prior book, that agriculture in the U.S. and Texas is sensitive in terms of land and water usages, as well as crop and livestock production. However, in terms of agricultural-based economic welfare, the simulated effects of climate change are not large. There will be regional displacements, with climate change as simulated here being a force to which Texas agriculture is vulnerable, particularly in the High Plains. We also find that under the climate change conditions simulated herein that statewide Texas cropped acreage declines by about 20 percent.

The nature of these results, particularly the overall resilience of agriculture to climate change is not entirely unexpected. The pattern is similar to the results of many earlier studies. The Edwards aquifer study also shows agriculture, intersectoral water competition and ecology are at issue.

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