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PNNL-12252

U.S. REGIONAL AGRICULTURAL PRODUCTION IN 2030 AND 2095: RESPONSE TO CO_2 FERTILIZATION AND HADLEY CLIMATE MODEL (HadCM2) PROJECTIONS OF GREENHOUSE-FORCED CLIMATIC CHANGE

R. César Izaurralde
Robert A. Brown
Norman J. Rosenberg

July 1999

Contribution to the Agricultural Sector Analysis, U.S. National Assessment of the Potential Consequences of Climate Variability and Change

Research supported by the U.S. Department of Energy Under Contract DE-AC06-76RLO 1830

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Executive Summary

Research activities underway to evaluate potential consequences of climate change and variability on the agriculture, water resources, and other U.S. sectors were mandated by the Global Change Research Act of 1990. These activities are being carried out in a public-private partnership under the guidance of the U.S. Global Change Research Program. Researchers at Pacific Northwest National Laboratory (PNNL) have been using integrated assessment methodologies to appraise the possible impacts of global warming and climatic variability on the behavior of managed and natural systems. This interim PNNL report contributes to the U.S. National Assessment process with an analysis of the modeled impacts of climatic changes projected by the Hadley/UKMO (HadCM2) general circulation model on agricultural productivity and selected environmental variables. The construction of climatic data for the simulation runs followed general guidelines established by the U.S. National Assessment Synthesis Team. The baseline climate data were obtained from national records for the period 1961 – 1990. The scenario runs for two future periods (2025 – 2034; 2090 – 2099) were extracted from results of a HadCM2 run distributed at a half-degree spatial resolution. The Erosion Productivity Impact Calculator (EPIC) was used to simulate the behavior of 204 "representative farms" (i.e., soil-climate-management combinations) under baseline climate, the two future periods and their combinations with two levels of atmospheric CO_2 concentrations (365 and 560 ppm).

Analysis of simulation results identified areas in Texas, New Mexico, Colorado, Utah, Arizona, and California that would experience large temperature increases by 2030. Slight cooling is expected by 2030 in parts of Alabama, Florida, Maine, Montana, Idaho, and Utah. Larger areas will experience increased warming by 2095. Uniform precipitation increases are expected by 2030 in the north eastern quarter of the country. These uniform precipitation increases are expected to expand to the eastern half of the country by 2095. Regional increases, decreases and no change in dryland corn yields were predicted under from future climate-change scenarios. Yield increases were predicted in the Lakes, Corn Belt and Northeast regions of the U.S. Increases in irrigated corn yields were predicted in almost all regions of the country. Soybean yields are anticipated to decrease in the Northern and Southern Plains, the Corn Belt, Delta, Appalachian, and Southeast regions. Soybean yields in the Lakes and Northeast regions should increase. Simulated winter wheat exhibited consistent trends of yield increase under scenarios of climate change.

Evapotranspiration in dryland corn is expected to increase under both scenarios of climate change. Water-use efficiency on dryland, however, would decrease by 2 – 4 kg ha^{-1} mm^{-1} under climate change. Surface runoff could decrease from baseline during the 2030 period and increase during the 2095 period. Dryland corn growing in 2030 would experience more days with water stress than it does under current climate.

Corn production is likely to change in 2030 and 2095 in the three currently most important producing regions of the country. In 2030, corn production is expected to increase in the Corn Belt and Lakes regions and to decrease in the Northern Plains. The overall impact would be a decrease in national production. National production of dryland winter wheat is likely to increase in both future periods.

Introduction

The U.S. National Assessment (US – NA) aims at gaining insight on the national and regional consequences of climate change and variability as well as at evaluating methods with which to adapt to its predicted effects. The activities underway have been mandated by the Global Change Research Act of 1990 (P.L. 101-606) under the guidance of the U.S. Global Change Research Program (USGCRP). Assessment activities are being conducted in a public-private partnership at regional and national scales on a broad range of economic and natural resource-based sectors (agriculture, coastal areas and marine resources, forests, health and water).

The agriculture sector analysis is concerned mainly with issues and economic implications related to agricultural production at national and regional scales. As stated, the analysis should consider the "financial vulnerability of farmers and farming regions, coping strategies which may be utilized to manage the impact of climate change, and possible impacts of climate change on environmental factors (soil erosion, wildlife habitat, livestock waste, and agricultural chemicals)" (U.S. National Assessment Synthesis Team, 1998).

Researchers at Pacific Northwest National Laboratory (PNNL) have been using an integrated-assessment modeling approach to evaluate the possible impacts of global warming and climatic variability on the behavior of managed and natural systems. A system of biophysical models including EPIC (Williams, 1995), HUMUS (Srinivasan et al., 1993) and BIOME3 (Haxeltine and Prentice, 1996) has provided the core computer capabilities to examine the magnitude and direction of these changes. EPIC has been used at PNNL to assess influences of a wide array of climate change scenarios based on General Circulation Model (GCM) (e.g., GISS, UKTR, BMRC and UIUC, Schlesinger/EMF) runs on U.S. dryland and irrigated cropland (Brown and Rosenberg; 1997, 1999) and to study North American crop sensitivity to climatic variability associated with the El Niño/La Niña phenomena (Izaurralde et al., 1999). In addition, Brown et al. (1999) have used a regionalized GCM scenario developed for the MINK (Missouri, Iowa, Nebraska and Kansas) region to evaluate the potential performance of switchgrass grown for biomass energy under conditions of global warming.

The objective of this report is to contribute to the US – NA with a preliminary national analysis of the modeled impacts of climatic changes projected by the Hadley/UKMO (HadCM2) GCM on agricultural productivity and selected environmental variables.

Materials and Methods

Climatic data

The general guidelines established by the U.S. National Assessment Synthesis Team (1998) of using *historical* and *scenario-driven* approaches were followed for designing and executing the simulation runs at PNNL. Historical data for the baseline runs were obtained from databases that reside in the Hydrological Unit Model for the United States [HUMUS] (Srinivasan et al., 1993) for the period 1961 – 1990. These data originate from daily records of temperature and precipitation from the national cooperative network of meteorological stations (Reek et al., 1992). The historical data in HUMUS are represented at an 8-digit USGS basin scale resolution for the conterminous U.S.

Climatic data for the scenario runs were provided in 8-mm tape format by the National Center for Atmospheric Research (NCAR) in December 1998. The data included results of a computer run with the HadCM2 GCM during the period 1994 - 2100. This transient, coupled, warm-started GCM run was generated assuming a 1% per year increase in CO_2 concentrations together with changes brought about by aerosol effects on albedo. As part of the VEMAP project (D. Schimel, pers. comm.) model run results were downscaled to a half-degree spatial resolution. The procedures followed for downscaling included methods to account for the effects of topography on temperature and precipitation.

Simulation model, input data and scenario runs

The EPIC model, adapted by Stockle et al. (1992) to account for CO_2 effects on photosynthesis and evapotranspiration, was used to simulate climate-change impacts on corn, wheat, soybean and alfalfa-hay yields. We used a set of "representative farms"[1] to quantitatively describe soil-climate-management conditions prevailing in each of the 204 4-digit Hydrological Unit Area (HUA) basins of the conterminous U.S. This set was originally developed as part of a NSF project (J.A. Edmonds and N.J. Rosenberg, NSF-MMIA Grant No. DEB-9634290) to project climatic change impacts on agriculture and water resources arising from BMRC and UIUC scenarios.

Climatic data for the scenario runs were developed as follow. The baseline scenario used the historical records for the period 1961 – 1990. Two HadCM2 scenarios for the periods 2025 – 2034 (H1) and 2090 – 2099 (H2) were built by extracting the data from the 8-mm tapes and reformatting these data as EPIC daily input files. The meteorological data extracted corresponded to grid cells located as close as possible to each HUA centroid. Each scenario was run under two conditions of atmospheric CO_2 stabilization: 365 and 560 ppm. Thus, a total of 4,896 runs (204 farms x 4 crops x 3 scenarios x 2 CO_2 levels) was executed. The output data extracted for analyses included: crop yield, standard deviation of crop yield, evapotranspiration, potential evapotranspiration, runoff, and number of stress days (water and temperature) affecting crop production.

Analysis of simulation results

Analyses of variance on all output variables were conducted at the regional level using the USDA Economic Research Service (USDA-ERS) production regions as the basis for aggregation (Fig. 1). Farms within each of 10 regions served as ANOVA replicates. Further analyses were conducted to evaluate the sensitivity of crop productivity to climatic change at the basin scale using annual yields as replicates.

[1] The concept of a representative farm is explained in Easterling et al. (1992).

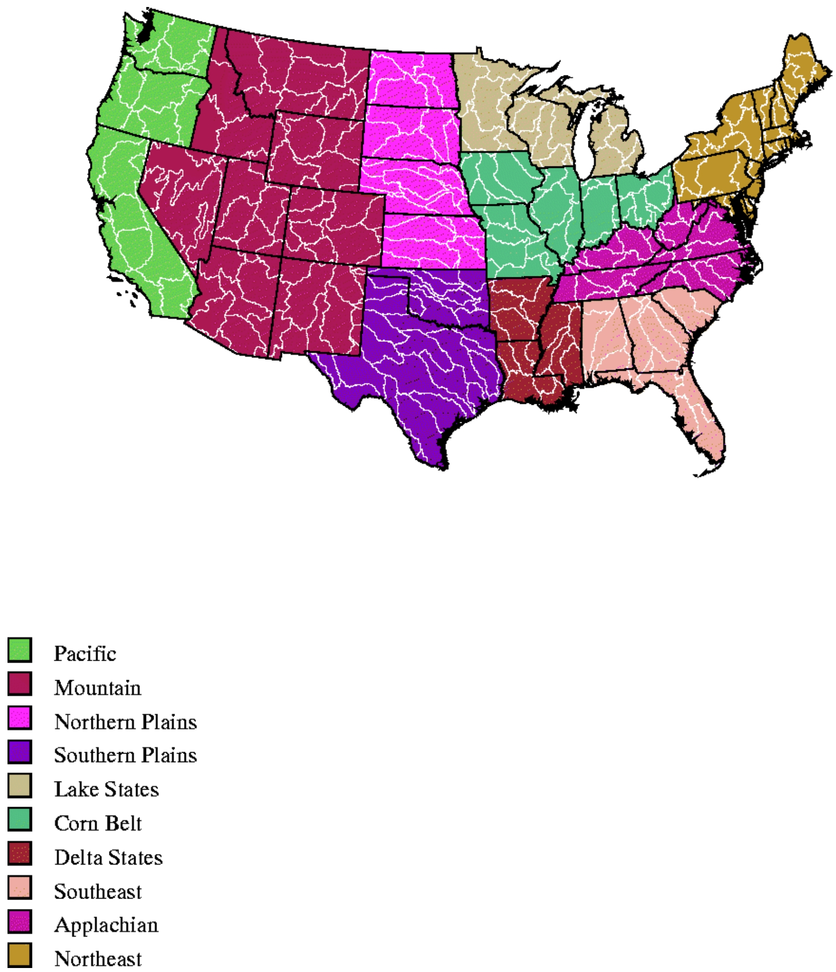

Fig. 1. USDA Economics Research Service agricultural regions (in color) drawn over the USGS 4-digit basins (boundaries delineated in white).

Results and Discussion

Simulated regional distribution of air temperature and precipitation deviations during two periods in the 21st century in the conterminous U.S.

According to HadCM2 simulation runs, average air temperature deviations from baseline are expected to reach up to 6.5 °C during 2025 – 2034 and expand beyond 7.0 °C during the last decade (2090 – 2099) of the 21st century (Fig. 2). During the first period, the largest temperature increases (> 2.5 °C) are predicted to occur in the southwest across the states of Texas, New Mexico, Colorado, Utah, Arizona, and California. Slight average cooling is expected in isolated regions in the East (Alabama, Florida, and Maine) and in mountainous regions in the West (Montana, Idaho, and Utah). Moderate warming (0 – 2.5 °C) is predicted for the rest of the country.

By 2095, the region with the most pronounced warming is expected to expand both in area and in magnitude when compared to the period starting in 2025. This region would then expand from the southwest into the Plains and the Pacific. Moderate warming is expected in most of the east as well at high altitudes in Nevada, Idaho, and Montana. As revealed by data in Table 1, the projected increases in average temperatures would develop more because of increases in their minima rather than in their maxima (Karl et al., 1993).

The distribution of projected annual precipitation changes by 2030 presents two distinct patterns (Fig. 3a). The first is characterized by rather uniform increases in precipitation across the NE quarter of the country (0 - 175 mm). In the rest of the country, basins with precipitation decreases mix with basins with precipitation increases. When aggregated over large regions (Table 1) precipitation deviations are mostly positive (4 – 126 mm) except in the Delta and Southeast regions where average decreases of –46 and –21 mm, respectively, are expected.

The HadCM2 simulations project a considerable wetter future by the end of the 21st century. The area with consistent precipitation increases extends now to the eastern half of the country (Fig. 3b) with regional average increases ranging from 154 to 288 mm (Table 1). The western half now shows a more consistent pattern of precipitation increases but the magnitudes do not extend to those projected in the eastern half except in California.

Regional analysis of crop productivity

Analysis of variance of crop yields simulated in each of the 10 U.S. agricultural regions as defined by the USDA Economic Research Service are presented in Table 2. The statistical model fitted considered two main effects (two CO_2 levels and three climate change scenario levels) and a simple interaction. The results suggest that most regions and crop-irrigation combinations were sensitive to the simulated climatic-change and CO_2-fertilization effects. A notable exception occurred in the Pacific region (Washington, Oregon and California) where the climate change main effect was not significant in the majority of the crop-irrigation combinations. Another region with a rather low sensitivity was the Southeast. The algorithms established for crop growth made corn, soybean and wheat very sensitive to the simulated changes in climate and CO_2 atmospheric concentration.

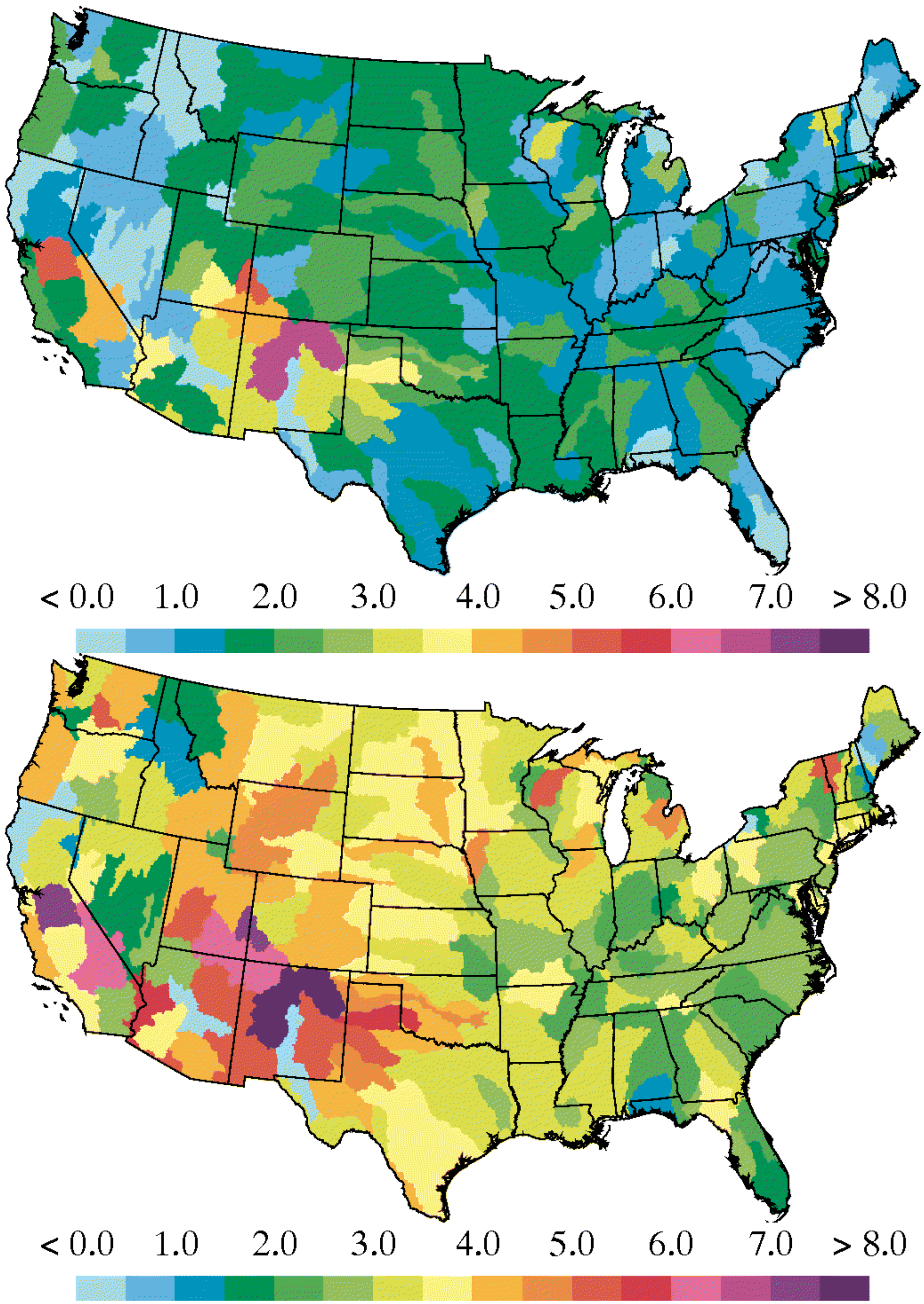

Fig. 2. Changes in average temperatures in (a) 2030 and (b) 2095 from baseline projected with the HadCM2 general circulation model.

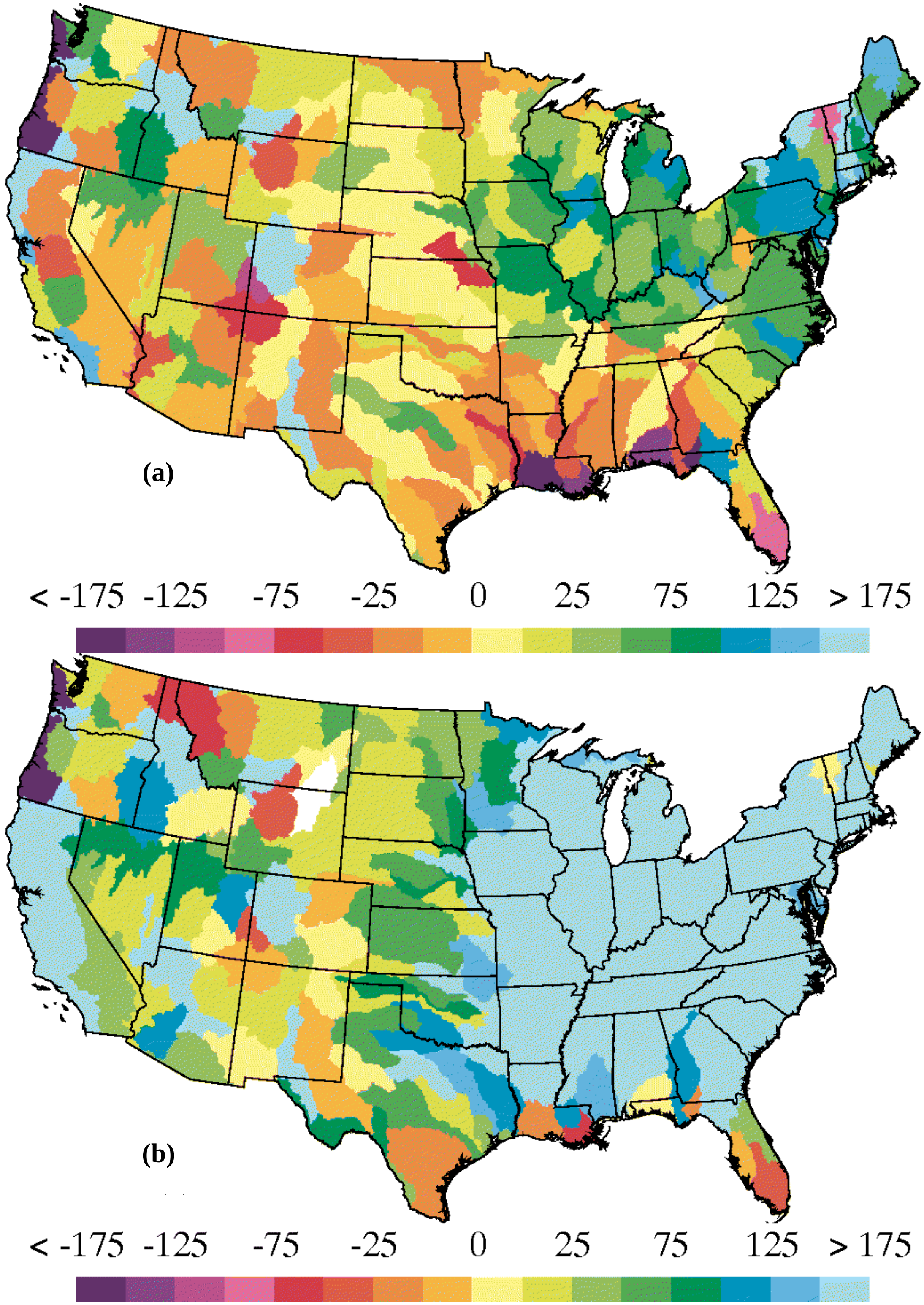

Fig. 3. Changes in annual precipitation in (a) 2030 and (b) 2095 from baseline projected with the HadCM2 general circulation model.

Table 1. Regional distribution of air temperature and precipitation under baseline conditions and deviations from baseline induced by the Hadley climate changes.

CO_2 / Scenario	Region									
	Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalachian	Southeast
	Maximum daily air temperature (ºC)									
1) B	**19.0**	**18.0**	**16.0**	**24.7**	**12.3**	**16.4**	**23.8**	**13.5**	**20.0**	**25.0**
2) H1	1.1	0.9	1.3	1.3	0.9	0.9	1.2	0.5	0.7	1.0
3) H2	2.9	2.7	2.7	3.1	2.4	2.0	2.2	2.0	1.7	2.0
	Minimum daily air temperature (ºC)									
1) B	**5.4**	**1.3**	**1.9**	**10.5**	**0.1**	**4.5**	**10.9**	**1.9**	**6.6**	**12.0**
2) H1	1.1	1.9	1.4	1.6	1.4	1.2	1.6	0.3	1.4	0.9
3) H2	3.5	4.5	3.6	3.7	3.7	3.2	3.1	2.5	3.2	2.4
	Precipitation (mm)									
1) B	**799**	**339**	**562**	**727**	**792**	**941**	**1383**	**1054**	**1215**	**1354**
2) H1	44	71	13	4	71	87	-46	126	64	-21
3) H2	164	120	79	88	219	254	194	288	275	154

Table 2. Statistical significance of the effects of three climate change scenarios (SCEN), two CO_2 levels (CO2) and their interactions on U.S. regional yields of corn, soybean, winter wheat and alfalfa. Corn and alfalfa are simulated with and without irrigation. The coefficient of variation (C.V.) of each experiment is also given.

	Regions																			
Effect	Pacific		Mountain		N. Plains		S. Plains		Lakes		Corn Belt		Delta		Northeast		Appalachian		Southeast	
	P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F	
Corn - *Dryland*																				
CO2	0.365	NS	0.004	*	0.002	*	0.003	*	0.001	*	0.000	*	0.077	*	0.016	*	0.011	*	0.094	*
SCEN	0.473	NS	0.004	*	0.002	*	0.009	*	0.000	*	0.000	*	0.684	NS	0.006	*	0.668	NS	0.432	NS
CO2xSC.	0.994	NS	0.898	NS	0.945	NS	0.936	NS	0.740	NS	0.743	NS	0.714	NS	0.929	NS	0.970	NS	0.979	NS
C.V. (%)	147.2		115.2		38.8		42.1		14.9		8.7		21.1		23.7		20.4		31.8	
Corn - *Irrigated*																				
CO2	0.380	NS	0.021	*	0.000	*	0.005	*	0.013	*	0.000	*	0.337	NS	0.049	*	0.052	*	0.142	NS
SCEN	0.172	NS	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.138	NS	0.000	*	0.694	NS	0.692	NS
CO2xSC.	0.994	NS	0.947	NS	0.871	NS	0.984	NS	0.940	NS	0.910	NS	0.989	NS	0.980	NS	0.994	NS	0.995	NS
C.V. (%)	46.3		28.8		7.6		14.6		13.9		6.4		24.7		22.6		21.6		31.0	
Soybean																				
CO2	0.063	*	0.001	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.003	*	0.000	*	0.005	*
SCEN	0.627	NS	0.026	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.012	*	0.155	NS	0.058	*
CO2xSC.	0.987	NS	0.949	NS	0.975	NS	0.503	NS	0.842	NS	0.943	NS	0.795	NS	0.955	NS	0.993	NS	0.994	NS
C.V. (%)	79.1		75.0		30.9		25.6		21.1		10.3		16.6		31.7		21.5		26.7	
Wheat																				
CO2	0.048	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.002	*
SCEN	0.559	NS	0.000	*	0.161	NS	0.082	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.309	NS
CO2xSC.	0.997	NS	0.873	NS	0.560	NS	0.931	NS	0.341	NS	0.678	NS	0.898	NS	0.699	NS	0.796	NS	0.974	NS
C.V. (%)	48.9		55.8		23.5		33.5		8.2		15.8		16.5		21.5		17.8		27.6	
Alfalfa - *Dryland*																				
CO2	0.095	*	0.001	*	0.000	*			0.000	*	0.000	*								
SCEN	0.567	NS	0.073	*	0.104	NS			0.000	*	0.105	NS								
CO2xSC.	0.983	NS	0.965	NS	0.963	NS			0.846	NS	0.974	NS								
C.V. (%)	77.0		25.2		57.6				23.5		29.8									
Alfalfa - *Irrigated*																				
CO2	0.000	*	0.000	*	0.000	*			0.000	*	0.000	*								
SCEN	0.000	*	0.000	*	0.000	*			0.000	*	0.000	*								
CO2xSC.	0.809	NS	0.597	NS	0.812	NS			0.712	NS	0.833	NS								
C.V. (%)	15.2		14.1		15.0				11.6		11.8									

The year-to-year variability within each study period was evaluated by conducting ANOVA on the regional standard deviations of crop yields as dependent variables of climate change and concentration of atmospheric CO_2 (Table 3). Corn yield variability was sensitive to the warming induced by climatic change but not to a CO_2-enriched atmosphere. The other three crops modeled, all of C3-type photosynthesis pathway, produced standard deviations that were sensitive –in most regions– to both climatic-change scenario and the CO_2 effect.

The lack of significant interactions between the climatic changes and CO_2 effects indicates that the modeled effects were additive, thus allowing for the interpretation of results based on main effect means. Based on this analysis, yields of dryland corn in the two future scenarios are expected to remain the same, increase or decrease in different regions of the country (Table 4, Fig. 4). For example, there was not enough sensitivity to detect any significant difference in the Pacific region which comprises the states of Washington, Oregon and California. Apparently, the high variability induced by the scenario - CO_2 - farm interactions precluded the detection of significant yield changes due to the modeled effects. Further analysis at a higher spatial resolution will be necessary to analyze this region.

The Mountain west is also a large region with low inherent productivity for corn. On average, dryland corn yields are predicted to decrease by 45% below baseline during the first future period but to recover late in the 21^{st} century. Significant yield reductions are also expected in both future periods in the Northern and Southern Plains, with these reductions somewhat attenuated by the CO_2 fertilization effect (see treatment means in Table 4).

Different results, however, were simulated for the northeastern regions of the country. Yield increases were predicted in future production of dryland corn in the Lakes, Corn Belt and Northeast regions of the U.S (Table 4, Fig. 4). These yield increases most likely arise from decreased low-temperature stress because of higher air temperatures. It is worth noting here that the increased warming predicted by HadCM2 would occur more due to increases in minimum temperatures than in maximum temperatures. For example in the Lakes region, the simulated "nocturnal warming" reached 1.4 and 3.1 °C during the two future periods while maximum temperatures increased only about 0.9 and 2.4 °C above baseline.

Assuming enough water for irrigation is available, our modeling work predicts that yields of irrigated corn would increase in almost all regions of the country including those where losses had been predicted under dryland conditions (e.g., Mountain and Northern Plains).

The analysis becomes more complex as we attempt to elucidate the overall regional impacts of climatic change on soybean production (Table 5). Yields are expected to decrease significantly in the Northern and Southern Plains, the Corn Belt, Delta, Appalachian, and Southeast regions. The reverse pattern of yield increase occurred only in the Lakes and Northeast regions of the U.S. The simulated yield trends in the Pacific and Mountain regions were either not significant or unclear.

Table 3. Statistical significance of the effects of three climate change scenarios (SCEN), two CO_2 levels (CO2) and their interactions on the standard deviations of U.S. regional yields of corn, soybean, winter wheat and alfalfa. Corn and alfalfa are simulated with and without irrigation. The coefficient of variation (C.V.) of each experiment is also given.

	Regions																			
Effect	Pacific		Mountain		N. Plains		S. Plains		Lakes		Corn Belt		Delta		Northeast		Appalachian		Southeast	
	P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F		P > F	
Corn - *Dryland*																				
CO2	0.317	NS	0.001	*	0.571	NS	0.485	NS	0.985	NS	0.795	NS	0.875	NS	0.943	NS	0.938	NS	0.727	NS
SCEN	0.040	*	0.000	*	0.000	*	0.016	*	0.000	*	0.000	*	0.008	*	0.000	*	0.065	*	0.000	*
CO2xSC.	0.835	NS	0.993	NS	0.722	NS	0.794	NS	0.859	NS	0.631	NS	0.875	NS	0.944	NS	0.929	NS	0.941	NS
C.V. (%)	112.5		78.3		36.5		35.2		47.2		31.2		42.2		44.6		44.5		33.6	
Corn - *Irrigated*																				
CO2	0.602	NS	0.432	NS	0.582	NS	0.556	NS	0.564	NS	0.283	NS	0.569	NS	0.408	NS	0.606	NS	0.436	NS
SCEN	0.044	*	0.052	*	0.641	NS	0.912	NS	0.000	*	0.000	*	0.740	NS	0.000	*	0.928	NS	0.641	NS
CO2xSC.	0.996	NS	0.981	NS	0.998	NS	0.993	NS	0.986	NS	0.970	NS	0.991	NS	0.997	NS	0.996	NS	0.989	NS
C.V. (%)	66.3		65.1		57.3		46.7		55.7		29.5		43.4		45.1		53.8		42.8	
Soybean																				
CO2	0.040	*	0.001	*	0.019	*	0.007	*	0.031	*	0.002	*	0.246	NS	0.015	*	0.051	*	0.077	*
SCEN	0.002	*	0.002	*	0.002	*	0.000	*	0.000	*	0.000	*	0.009	*	0.000	*	0.000	*	0.000	*
CO2xSC.	0.799	NS	0.929	NS	0.695	NS	0.899	NS	0.783	NS	0.768	NS	0.978	NS	0.919	NS	0.903	NS	0.866	NS
C.V. (%)	60.0		63.4		34.4		31.5		30.3		20.0		43.8		31.4		27.1		29.2	
Wheat																				
CO2	0.108	NS	0.000	*	0.000	*	0.003	*	0.017	*	0.001	*	0.024	*	0.013	*	0.022	*	0.001	*
SCEN	0.001	*	0.235	NS	0.000	*	0.763	NS	0.000	*	0.000	*	0.117	NS	0.000	*	0.165	NS	0.000	*
CO2xSC.	1.000	NS	0.986	NS	0.607	NS	0.745	NS	0.997	NS	0.739	NS	0.952	NS	0.922	NS	0.943	NS	0.897	NS
C.V. (%)	56.5		55.5		24.0		29.7		27.0		26.0		28.0		32.3		35.0		22.4	
Alfalfa - *Dryland*																				
CO2	0.010	*	0.000	*	0.005	*			0.004	*	0.024	*								
SCEN	0.124	NS	0.014	*	0.398	NS			0.001	*	0.000	*								
CO2xSC.	0.949	NS	0.943	NS	0.950	NS			0.852	NS	0.776	NS								
C.V. (%)	58.1		47.5		34.2				24.0		29.2									
Alfalfa - *Irrigated*																				
CO2	0.165	NS	0.044	*	0.040	*			0.002	*	0.032	*								
SCEN	0.638	NS	0.439	NS	0.000	*			0.002	*	0.006	*								
CO2xSC.	0.988	NS	0.994	NS	0.903	NS			0.966	NS	0.989	NS								
C.V. (%)	53.1		69.7		41.3				24.0		31.5									

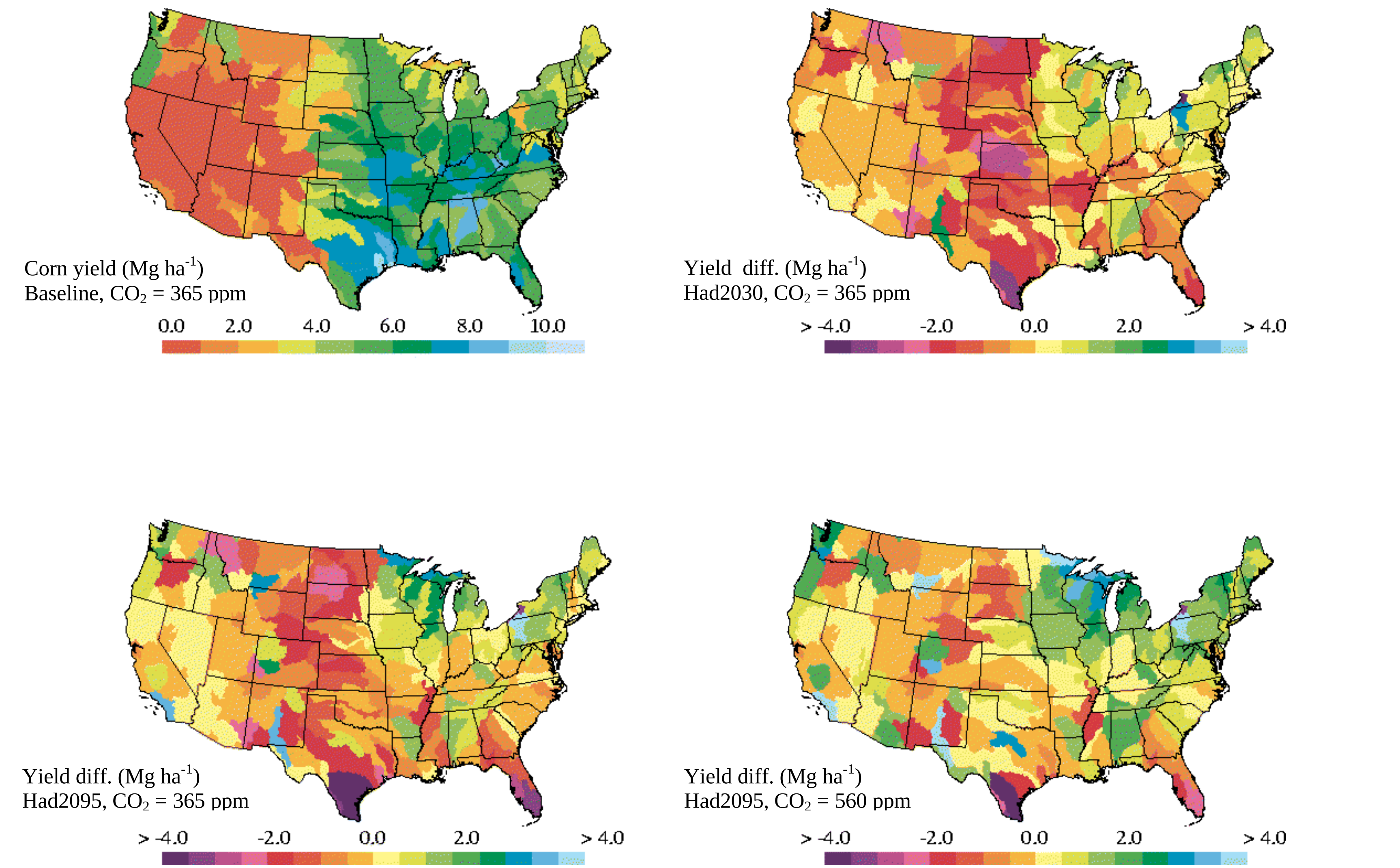

Fig. 4. Simulated yield changes from baseline for dryland corn grown in (a) 2030 and (b) 2095 under climate scenarios projected with the HadCM2 general circulation model.

Table 4. Simulated yields of dryland and irrigated corn under baseline climate (B) and two HadCM2 projections in 2030 (H1) and 2095 (H2), each at two CO_2 concentration levels (365 and 560 ppm).

CO_2 / Scenario	Region: Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalachian	Southeast
	---Mg ha^{-1}---									
Main effect means										
Dryland										
1) 365	1.39 a[†]	0.75 b	3.73 b	4.69 b	5.30 b	6.30 b	5.98 b	4.56 b	6.11 b	5.38 b
2) 560	1.80 a	1.13 a	4.72 a	5.88 a	5.86 a	6.87 a	6.54 a	5.04 a	6.79 a	6.08 a
1) B	1.61 a	1.19 a	5.02 a	6.13 a	4.76 c	6.29 b	6.41 a	4.35 b	6.43 a	6.05 a
2) H1	1.25 a	0.65 b	3.65 b	5.02 b	5.62 b	6.64 a	6.29 a	4.97 a	6.32 a	5.73 a
3) H2	1.93 a	0.97 a	4.00 b	4.72 b	6.37 a	6.81 a	6.08 a	5.08 a	6.61 a	5.40 a
Irrigated										
1) 365	5.80 a	5.22 b	6.14 b	7.41 b	5.63 b	6.51 b	6.34 a	4.78 b	6.47 b	5.68 a
2) 560	6.27 a	5.67 a	6.60 a	7.97 a	6.04 a	6.98 a	6.70 a	5.17 a	7.04 a	6.30 a
1) B	5.59 b	4.65 b	5.86 c	7.96 a	4.82 c	6.37 b	6.30 ba	4.41 b	6.58 a	6.08 a
2) H1	5.77 ba	5.76 a	6.77 a	8.11 a	6.03 b	6.94 a	7.06 a	5.23 a	6.87 a	6.15 a
3) H2	6.75 a	5.92 a	6.48 b	7.00 b	6.65 a	6.93 a	6.21 b	5.29 a	6.82 a	5.74 a
Treatment means										
Dryland										
B-365	1.38 a	0.98 bc	4.60 ba	5.55 b	4.57 d	6.05 c	6.26 ba	4.16 d	6.13 bc	5.76 ba
B-560	1.83 a	1.40 a	5.44 a	6.70 a	4.95 dc	6.53 b	6.55 ba	4.54 dc	6.73 ba	6.35 a
H1-365	1.08 a	0.51 d	3.11 d	4.33 c	5.30 c	6.31 cb	5.84 b	4.70 bdc	5.94 c	5.34 ba
H1-560	1.42 a	0.80 dc	4.20 bc	5.70 ba	5.94 b	6.98 a	6.74 a	5.24 ba	6.70 ba	6.13 ba
H2-365	1.71 a	0.76 dc	3.48 dc	4.20 c	6.04 b	6.53 b	5.84 b	4.81 bac	6.27 bac	5.04 b
H2-560	2.15 a	1.18 ba	4.51 b	5.23 bc	6.69 a	7.09 a	6.32 ba	5.35 a	6.95 a	5.76 ba
Irrigated										
B-365	5.39 b	4.47 c	5.66 d	7.70 bc	4.65 d	6.15 c	6.14 b	4.24 c	6.32 b	5.80 a
B-560	5.79 ba	4.82 c	6.05 c	8.22 ba	4.98 d	6.58 b	6.45 ba	4.57 bc	6.85 ba	6.36 a
H1-365	5.53 ba	5.53 b	6.52 b	7.81 bc	5.82 c	6.69 b	6.84 ba	5.02 ba	6.57 ba	5.82 a
H1-560	6.01 ba	6.00 ba	7.02 a	8.41 a	6.24 cb	7.20 a	7.28 a	5.44 a	7.17 a	6.48 a
H2-365	6.48 ba	5.67 ba	6.24 c	6.72 d	6.42 b	6.68 b	6.03 b	5.08 ba	6.52 ba	5.42 a
H2-560	7.02 a	6.17 a	6.72 b	7.27 dc	6.89 a	7.17 a	6.38 ba	5.50 a	7.11 ba	6.06 a

[†] Means within a column and section followed by the same letter are not significantly different at the 10% level of probability.

Table 5. Simulated soybean yields under baseline climate (B) and two HadCM2 projections in 2030 (H1) and 2095 (H2), each at two CO_2 concentration levels (365 and 560 ppm).

CO_2 / Scenario	Pacific		Mountain		N. Plains		S. Plains		Lakes		Corn Belt		Delta		Northeast		Appalachian		Southeast	
	---Mg ha^{-1}---																			
Main effect means																				
1) 365	0.62	b†	0.44	b	1.25	b	1.21	b	1.54	b	1.88	b	1.52	b	1.29	b	1.73	b	1.42	b
2) 560	0.82	a	0.60	a	1.60	a	1.55	a	1.83	a	2.20	a	1.78	a	1.53	a	2.05	a	1.69	a
1) B	0.70	a	0.57	a	1.71	a	1.80	a	1.48	c	2.15	a	1.88	a	1.30	b	2.00	a	1.71	a
2) H1	0.67	a	0.43	b	1.27	b	1.26	b	1.67	b	1.99	b	1.65	b	1.36	b	1.86	ba	1.51	b
3) H2	0.79	a	0.55	a	1.29	b	1.09	c	1.91	a	1.98	b	1.42	c	1.57	a	1.82	b	1.44	b
Treatment means																				
B-365	0.61	ba	0.49	cb	1.52	b	1.58	b	1.36	e	1.99	c	1.75	b	1.20	d	1.84	bc	1.58	ba
B-560	0.80	ba	0.66	a	1.90	a	2.01	a	1.59	cd	2.31	a	2.01	a	1.40	cbd	2.16	a	1.84	a
H1-365	0.57	b	0.36	c	1.10	c	1.10	dc	1.52	ed	1.82	d	1.50	dc	1.24	cd	1.69	c	1.37	bc
H1-560	0.76	ba	0.50	b	1.45	b	1.43	b	1.82	b	2.16	b	1.81	b	1.48	b	2.02	ba	1.65	a
H2-365	0.68	ba	0.46	cb	1.12	c	0.96	d	1.75	cb	1.83	d	1.32	d	1.44	cb	1.67	c	1.31	c
H2-560	0.91	a	0.64	a	1.46	b	1.21	c	2.07	a	2.13	b	1.53	c	1.70	a	1.98	ba	1.58	bac

† Means within a column and section followed by the same letter are not significantly different at the 10% level of probability.

Simulated winter wheat shows consistent trends of yield increase, statistically significant in most cases, under the scenarios of climate change across the U.S (Table 6, Fig. 5). A significant reversal occurred in the Southern Plains where the highest yields were predicted during the baseline period and that beginning in 2025. The region is projected to experience average yield losses of about 0.6 Mg ha^{-1} during the 10-year period beginning in 2090.

Hay crops simulated for the five regions detailed in Table 7 also exhibited contrasting responses to the projected climate changes. Modeled dryland hay production in the Pacific region was not sensitive to the anticipated changes in temperature and precipitation (Figs. 2 and 3). In contrast, the significant increases in dryland hay yield projected for the Southern Plains and Corn Belt regions accompanying changes in climatic variables are ascribed to interactions with soil-landscape characteristics.

Basin analysis

Additional statistical analyses were conducted to analyze climatic change and CO_2 fertilization effects likely to occurr at each farm within a 4-digit basin. We conducted ANOVA analysis for each farm using annual yields as replicate measures of the modeled effects. For the four climate change – CO_2 combinations the modeled yield difference was statistically significant at the 10% level of confidence in 59 - 74% of the cases. Without considering the CO_2 fertilization effect the modeled yield differences were significant on 68% of the farms for the period starting 2030 and increased to 70% for that starting in 2090. We conclude that the models in use have enough sensitivity to detect climatic changes.

Changes in evapotranspiration, runoff and plant stress in dryland corn

Evapotranspiration in dryland corn is expected to increase in both future periods in response to the warming projected by HadCM2 runs (Table 8). The largest increases by 2030 would register in the east (91 – 210 mm) while those in the west would be more modest (32 – 81 mm). By 2095, the increases in evapotranspiration in the west would be much more pronounced than in the east, at times more than doubling it as in the Pacific region. We surmise that these differential changes in evapotranspiration could arise from dissimilar patterns of relative changes in precipitation between regions. A current atmosphere enriched in CO_2 would reduce evapotranspiration of dryland corn by as little as 2 mm in the Pacific region and by as much as 31 mm in the Delta region. In the projected futures, the presence of a CO_2 fertilization effect would moderate the projected increases in evapotranspiration in western regions (e.g., Northern Plains) but augment those in eastern regions (e.g., Northeast).

Water-use efficiency (WUE), the ratio between economic crop yield and evapotranspiration, expresses the effectiveness with which a crop might be able to respond to changes in climate and CO_2 concentration. The range in WUE varied more than threefold from 3.2 kg ha^{-1} mm^{-1} in the Mountain region to 10.9 kg ha^{-1} mm^{-1} in the Appalachian region (Table 8). With no change in crop cultivar, corn is expected to use water less efficiently than in the present. The decreases in WUE by 2030 without CO_2 effect would range from 1.6 to 3.5 kg ha^{-1} mm^{-1}. The presence of a CO_2 effect would

Table 6. Simulated winter wheat yields under baseline climate (B) and two HadCM2 projections in 2030 (H1) and 2095 (H2), each at two CO_2 concentration levels (365 and 560 ppm).

CO_2 /	Region																			
Scenario	Pacific		Mountain		N. Plains		S. Plains		Lakes		Corn Belt		Delta		Northeast		Appalachian		Southeast	
	--Mg ha^{-1}--																			
	Main effect means																			
1) 365	3.62	b[†]	2.00	b	3.06	b	3.54	b	3.71	b	3.57	b	4.31	b	3.63	b	3.97	b	3.48	b
2) 560	4.37	a	2.68	a	3.93	a	4.43	a	4.39	a	4.23	a	5.11	a	4.34	a	4.74	a	4.25	a
1) B	3.72	a	2.14	b	3.40	ba	4.18	a	3.32	c	3.11	c	4.05	b	3.10	c	3.54	c	3.60	a
2) H1	4.07	a	2.06	b	3.37	b	4.15	a	4.33	b	4.17	b	5.10	a	4.19	b	4.59	b	4.00	a
3) H2	4.20	a	2.81	a	3.71	a	3.61	b	4.51	a	4.41	a	4.97	a	4.66	a	4.93	a	4.00	a
	Treatment means																			
B-365	3.37	b	1.84	c	3.09	c	3.75	bc	3.05	d	2.85	d	3.71	c	2.83	E	3.23	d	3.25	c
B-560	4.08	ba	2.44	b	3.71	b	4.61	a	3.59	c	3.37	c	4.40	b	3.37	d	3.86	c	3.96	ba
H1-365	3.68	ba	1.74	c	2.90	c	3.65	bc	3.96	b	3.81	b	4.65	b	3.82	c	4.18	cb	3.58	bc
H1-560	4.45	a	2.38	b	3.85	ba	4.66	a	4.70	a	4.53	a	5.54	a	4.57	b	5.01	a	4.42	a
H2-365	3.81	ba	2.42	b	3.20	c	3.21	c	4.13	b	4.04	b	4.56	b	4.24	cb	4.50	b	3.61	bc
H2-560	4.59	a	3.21	a	4.21	a	4.02	ba	4.89	a	4.79	a	5.39	a	5.08	a	5.37	a	4.39	a

[†] Means within a column and section followed by the same letter are not significantly different at the 10% level of probability.

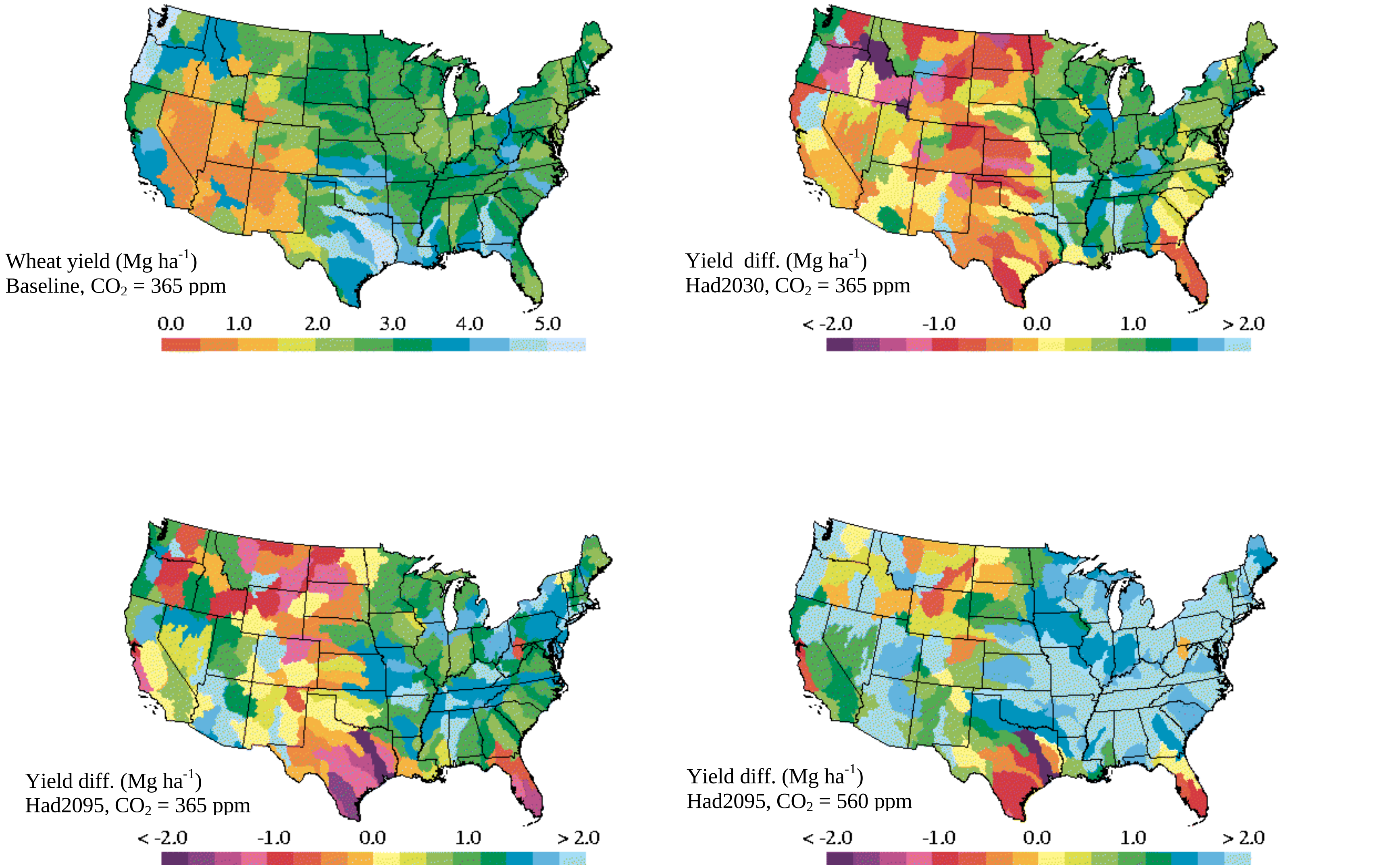

Fig. 5. Simulated yield changes from baseline for winter wheat grown in (a) 2030 and (b) 2095 under climate scenarios projected with the HadCM2 general circulation model.

Table 7. Simulated dryland and irrigated alfalfa yields under baseline climate (B) and two HadCM2 projections in 2030 (H1) and 2095 (H2), each at two CO_2 concentration levels (365 and 560 ppm).

	Region †									
Scenario	Pacific		Mountain		N. Plains		S. Plains		Corn Belt	
	----------Mg ha^{-1}----------									
Main effect means										
Dryland										
1) 365	4.67	b	3.26	b	5.14	b	7.63	b	8.51	b
2) 560	6.00	a	4.25	a	6.66	a	9.22	a	10.14	a
1) B	4.93	a	3.54	b	6.30	a	7.48	c	8.34	c
2) H1	5.16	a	3.57	b	5.42	b	8.64	b	9.54	b
3) H2	5.92	a	4.15	a	5.99	ba	9.15	a	10.10	a
Irrigated										
1) 365	11.58	b	10.35	b	8.91	b	8.49	b	9.10	b
2) 560	13.68	a	12.14	a	10.47	a	9.89	a	10.58	a
1) B	11.63	b	9.97	b	8.36	b	7.75	b	8.63	b
2) H1	13.00	a	11.85	a	10.17	a	9.83	a	10.38	a
3) H2	13.24	a	11.91	a	10.55	a	10.00	a	10.52	a
Treatment means										
Dryland										
B-365	4.34	b	3.08	c	5.57	bc	6.85	c	7.66	c
B-560	5.52	ba	4.00	ba	7.02	a	8.11	b	9.03	b
H1-365	4.51	ba	3.09	c	4.68	c	7.76	b	8.64	b
H1-560	5.81	ba	4.05	ba	6.16	ba	9.53	a	10.44	a
H2-365	5.15	ba	3.60	bc	5.17	c	8.27	b	9.23	b
H2-560	6.68	a	4.69	a	6.81	a	10.03	a	10.97	a
Irrigated										
B-365	10.70	d	9.21	c	7.71	c	7.17	d	7.99	c
B-560	12.57	bc	10.73	b	9.01	b	8.32	c	9.27	b
H1-365	11.92	dc	10.90	b	9.35	b	9.07	cb	9.58	b
H1-560	14.08	ba	12.80	a	10.98	a	10.59	a	11.17	a
H2-365	12.11	dc	10.94	b	9.69	b	9.23	b	9.72	b
H2-560	14.37	a	12.87	a	11.41	a	10.77	a	11.31	a

† Means within a column and section followed by the same letter are not significantly different at the 10% level of probability.

Table 8. Regional distribution of evapotranspiration, water-use efficiency and runoff under baseline conditions and their deviations from baseline induced by climate – CO_2 concentration changes.

CO_2 /	Region									
Scenario	Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalachian	Southeast
					Evapotranspiration (mm) in dryland corn					
B-365	**318**	**307**	**501**	**568**	**446**	**581**	**705**	**454**	**564**	**533**
B-560	-7	-2	-16	-17	-23	-27	-31	-18	-20	-19
H1-365	81	32	49	60	210	201	173	191	161	91
H1-560	75	30	43	53	183	171	152	170	140	71
H2-365	131	77	98	89	247	226	206	211	186	100
H2-560	124	75	90	74	218	193	174	190	163	79
					Water use efficiency (kg ha^{-1} mm^{-1}) in dryland corn					
B-365	**4.3**	**3.2**	**9.2**	**9.8**	**10.2**	**10.4**	**8.9**	**9.2**	**10.9**	**10.8**
B-560	5.9	4.6	11.2	12.2	11.7	11.8	9.7	10.4	12.4	12.4
H1-365	2.7	1.5	5.7	6.9	8.1	8.1	6.7	7.3	8.2	8.6
H1-560	3.6	2.4	7.7	9.2	9.4	9.3	7.9	8.4	9.5	10.1
H2-365	3.8	2.0	5.8	6.4	8.7	8.1	6.4	7.2	8.4	8.0
H2-560	4.9	3.1	7.6	8.1	10.1	9.2	7.2	8.3	9.6	9.4
					Runoff (mm) in dryland corn					
B-365	**153**	**21**	**35**	**86**	**120**	**156**	**384**	**230**	**181**	**108**
B-560	1	0	3	4	2	5	10	2	3	1
H1-365	-3	20	-15	-33	-38	-17	-105	-10	-30	-16
H1-560	-3	20	-14	-31	-34	-11	-99	-7	-26	-15
H2-365	21	16	-4	-5	-18	30	32	24	26	18
H2-560	22	16	-3	-1	-14	38	44	28	30	20

effectively cut in half (0.7 – 1.5 kg ha^{-1} mm^{-1}) the modeled decreases in WUE. A similar analysis can be derived for the period starting in 2090.

The regional pattern of change in runoff is more complex. Surface runoff could increase or decrease across regions within a period and do the same across periods within a region (Table 8). The expected general trend, however, is for runoff to decrease from baseline during the 2030 period and to increase during the 2095 period. Runoff appears to be only slightly sensitive to changes in atmospheric CO_2 concentrations. These findings agree with modeling work by Hulme et al. (1999) for projected changes in hydrology in Europe using HadCM2 runs.

Our analysis also indicates that corn crops growing in 2030 would experience more days with water stress than under current climatic conditions (Table 9). As with other plant water-related variables, an increase in atmospheric CO_2 concentration would moderate the increase in water stress days by one to two thirds of the projected figures. The widespread precipitation increases projected at the end of the 21st century lessen the increase in water stress days or even reduce them slightly below baseline. The most noticeable changes in simulated temperature stress days occurred in the Pacific, Mountain, Lakes, and Appalachian regions. These decreases ranged from 2 to 13 days. Increases in number of temperature stress days were rather moderate.

Changes in regional / national production potentials of dryland corn

While changes in future yields provide insight as to how crops would respond to potential changes in climate, they provide little information in terms of aggregate production at the regional or national levels. We attempt here to provide such analysis by "recreating" the national production of dryland corn under current and future climates with simulated yield results together with recent information on area planted to corn and winter wheat and subsequently harvested. The planted and harvested areas were obtained from the USDA Economics and Statistics System (USDA-ESS) (http://usda.mannlib.cornell.edu/) for the years 1998 – 1999 for corn (Table 10) and for 1996 – 1998 for winter wheat (Table 11). The state-by state information was aggregated up to the region level. Regional production for the different scenarios was obtained by multiplying the value of simulated yield by the harvested area. National production of corn and wheat were calculated by adding the regional values. The simulated national dryland corn yield was estimated by a weighted-average procedure using harvested area as the weighting factor.

The three largest simulated corn-producing regions are the Corn Belt, Lakes and Northern Plains (Table 10). The estimated national corn production of about 152,400,000 Mg was 64% of the average reported for the period 1996 – 1998 and 80% when compared to that for 1988 – 1992. One reason for the difference in estimates arising from the simulated national corn production and that reported by USDA-ESS is that the latter includes both dryland and irrigated corn production. Another reason is that the simulated values for the three largest producing regions were noticeably lower than those resulted when aggregating county-level data. Nevertheless, there was a strong relationship between simulated and reported regional corn production (y = 1.428x; r^2 = 0.983*; n = 8). This comparison excluded data for the Pacific and Mountain regions

Table 9. Regional distribution of water and temperature stress days under baseline conditions and their deviations from baseline induced by climate – CO_2 concentration changes.

CO_2 / Scenario	Region									
	Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalachian	Southeast
					Water stress days (d)					
B-365	**44.2**	**45.7**	**15.0**	**19.4**	**2.6**	**6.1**	**4.9**	**7.7**	**20.9**	**21.5**
B-560	-4.8	-4.9	-5.7	-5.6	-1.2	-0.8	-1.4	-1.0	-2.0	-1.8
H1-365	5.9	8.1	16.9	12.4	5.1	3.2	12.2	2.9	4.9	11.7
H1-560	1.7	4.2	10.9	6.0	2.5	0.8	7.8	1.1	2.1	8.2
H2-365	1.8	-1.6	9.6	5.5	3.4	0.7	4.3	2.4	1.1	8.9
H2-560	-2.3	-5.3	4.4	0.4	0.9	-0.5	1.3	0.8	-1.2	6.1
					Temperature stress days (d)					
B-365	**36.4**	**34.7**	**20.7**	**13.6**	**45.0**	**16.1**	**4.8**	**28.3**	**17.8**	**8.4**
B-560	1.2	1.1	0.9	0.3	0.3	0.3	-0.2	0.1	0.1	0.0
H1-365	-5.0	-3.3	0.6	1.0	-2.8	4.6	2.5	1.3	-6.0	0.5
H1-560	-4.1	-2.4	1.7	1.6	-1.9	5.0	3.0	1.6	-5.8	0.5
H2-365	-13.1	-6.6	-0.8	2.9	-12.2	1.7	3.7	-1.2	-8.9	-0.5
H2-560	-12.6	-6.0	0.1	3.8	-11.8	2.1	4.2	-1.0	-8.7	-0.5

Table 10. Changes in regional / national production potentials of dryland corn associated with Hadley 2030 (H1) and Hadley 2095 (H2) scenarios.

Scenario / Area (ha)	Region										
	Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalach.	Southeast	U.S.
	Dryland corn yields (Mg ha^{-1})										
B-365	1.38	0.98	4.60	5.55	4.57	6.05	6.26	4.16	6.13	5.76	5.32
B-560	1.83	1.40	5.44	6.70	4.95	6.53	6.55	4.54	6.73	6.35	5.88
H1-365	1.08	0.51	3.11	4.33	5.30	6.31	5.84	4.70	5.94	5.34	5.20
H1-560	1.42	0.80	4.20	5.70	5.94	6.98	6.74	5.24	6.70	6.13	5.98
H2-365	1.71	0.76	3.48	4.20	6.04	6.53	5.84	4.81	6.27	5.04	5.52
H2-560	2.15	1.18	4.51	5.23	6.69	7.09	6.32	5.35	6.95	5.76	6.21
	1998 – 1999 area (ha x 10^3) planted to corn and harvested and the ratio of harvested / planted										
Planted	333	720	6,644	1,002	5,304	14,160	487	1,475	1,361	456	31,943
Harvested	185	387	6,051	843	4,590	13,632	440	1,125	1,056	318	28,629
Harv./Plant.	0.56	0.54	0.91	0.84	0.87	0.96	0.90	0.76	0.78	0.70	0.89
	Regional and national dryland corn production (Mg x 10^3)										
B-365	256	379	27,823	4,677	20,967	82,535	2,757	4,683	6,469	1,833	152,379
B-560	340	544	32,939	5,650	22,700	89,045	2,885	5,104	7,105	2,021	168,332
H1-365	200	196	18,800	3,652	24,318	85,971	2,572	5,292	6,275	1,699	148,973
H1-560	263	310	25,426	4,807	27,250	95,159	2,969	5,896	7,078	1,952	171,109
H2-365	317	295	21,055	3,541	27,709	89,045	2,570	5,415	6,621	1,603	158,171
H2-560	399	458	27,305	4,407	30,731	96,644	2,783	6,017	7,333	1,832	177,909
	Regional and national production deviations from baseline (Mg x 10^3)										
B-560	84	164	5,116	973	1,734	6,509	127	421	637	188	15,953
H1-365	-56	-183	-9,023	-1,025	3,351	3,435	-186	609	-194	-135	-3,406
H1-560	8	-70	-2,397	129	6,284	12,623	211	1,213	609	119	18,730
H2-365	61	-85	-6,768	-1,136	6,743	6,509	-187	732	152	-230	5,792
H2-560	143	79	-518	-270	9,764	14,109	26	1,334	864	-1	25,530

Table 11. Changes in regional / national production potentials of dryland winter wheat associated with Hadley 2030 (H1) and Hadley 2095 (H2) scenarios.

Scenario / Area (ha)	Region										
	Pacific	Mountain	N. Plains	S. Plains	Lakes	Corn Belt	Delta	Northeast	Appalach.	Southeast	U.S.
	Dryland winter wheat yields (Mg ha^{-1})										
B-365	3.37	1.84	3.09	3.75	3.05	2.85	3.71	2.83	3.23	3.25	3.19
B-560	4.08	2.44	3.71	4.61	3.59	3.37	4.4	3.37	3.86	3.96	3.88
H1-365	3.68	1.74	2.9	3.65	3.96	3.81	4.65	3.82	4.18	3.58	3.33
H1-560	4.45	2.38	3.85	4.66	4.7	4.53	5.54	4.57	5.01	4.42	4.22
H2-365	3.81	2.42	3.2	3.21	4.13	4.04	4.56	4.24	4.5	3.61	3.43
H2-560	4.59	3.21	4.21	4.02	4.89	4.79	5.39	5.08	5.37	4.39	4.30
	1996 – 1998 area (ha x 10^3) planted to winter wheat and harvested and the ratio of harvested / planted										
Planted	1480	2551	6137	5196	326	1930	558	276	919	315	19687
Harvested	1397	2220	5391	3536	304	1707	520	265	723	273	16335
Harv./Plant.	0.94	0.87	0.88	0.68	0.93	0.89	0.93	0.96	0.79	0.87	0.83
	Regional and national winter wheat production (Mg x 10^3)										
B-365	4,705	4,094	16,731	13,256	928	4,905	1,923	749	2,335	887	50,512
B-560	5,696	5,429	20,088	16,296	1,092	5,800	2,280	892	2,791	1,080	61,444
H1-365	5,137	3,871	15,702	12,903	1,205	6,557	2,410	1,011	3,022	977	52,795
H1-560	6,212	5,295	20,846	16,473	1,430	7,796	2,871	1,210	3,622	1,206	66,961
H2-365	5,319	5,384	17,326	11,347	1,256	6,953	2,363	1,122	3,253	985	55,310
H2-560	6,408	7,142	22,795	14,211	1,488	8,244	2,793	1,345	3,882	1,197	69,505
	Regional and national production deviations from baseline (Mg x 10^3)										
B-560	991	1,335	3,357	3,040	164	895	358	143	455	194	10,932
H1-365	433	-222	-1,029	-353	277	1,652	487	262	687	90	2,283
H1-560	1,508	1,201	4,115	3,217	502	2,891	948	461	1,287	319	16,449
H2-365	614	1,290	596	-1,909	329	2,048	441	373	918	98	4,798
H2-560	1,703	3,048	6,064	954	560	3,339	871	596	1,547	311	18,993

because it was assumed that corn in those regions is produced largely under irrigation. Similarly, a simulated national corn yield of 5.32 Mg ha^{-1} was 73% of the USDA-ESS national average for the period 1996 – 1998 and 76% when compared with that for 1988 – 1992.

While recognizing the complexity in attempting to recreate national and regional patterns of crop production with simulation models and databases, these results appear to set a realistic baseline from which to project future changes in corn production. The data in Table 10 suggest that of the three most important regions, two would be affected positively (Corn Belt and Lakes) and one negatively (Northern Plains). The negative impact during the first future period –without considering the CO_2 fertilization effect– would offset any increase in the other major regions and cause an overall decrease in the national production of corn. Again, the yield changes and the area under corn of these three regions would dominate the changes predicted by the end of the 21st century, this time with a moderate increase in production. Further analysis would be required to include the impacts on production of possible shifts in producing areas induced by climatic change.

Similarly for winter wheat, the four largest simulated producing regions were the Northern and Southern Plains together with the Corn Belt and Pacific regions (Table 11). The national estimate of 50,512,000 Mg was 9% greater than the national average reported for 1996 – 1998. It is likely that these improvements in production estimates arise because wheat in the U.S. is grown mostly under dryland conditions. The relationship between simulated and reported production for all 10 regions was also strong (y = 0.825x; r^2 = 0.811*; n = 10). Regional wheat production was overestimated in the Northern and Southern Plains while it was underestimated in the Pacific, Mountain and Corn Belt regions.

The data in Table 11 reveal the Northern and Southern Plains as two regions where production during the 21st century could decrease or increase, depending on how CO_2 concentration ultimately impacts wheat growth. The space-time domain with a chance for a surprise is the Southern Plains in 2095. At the national level, production of dryland winter wheat is likely to increase in both future periods. As with corn, further analysis would be required to analyze how shifts in production areas could impact wheat production.

Summary

- The largest temperature increases by 2030 were predicted in Texas, New Mexico, Colorado, Utah, Arizona, and California
- Slight average cooling is expected by 2030 in isolated regions of Alabama, Florida, Maine, Montana, Idaho, and Utah. The temperature increases are projected to expand both in area and magnitude by 2095
- Increases in average temperatures would develop more because of increases in their minima rather than in their maxima
- Uniform precipitation increases are expected by 2030 in the NE quarter of the country. These uniform precipitation increases are expected to expand to the eastern half of the country by 2095
- Most regions and crop-irrigation combinations were sensitive to the simulated climatic-change and CO_2-fertilization effects

- Corn yield variability was sensitive to the warming induced by climatic change but not to a CO_2-enriched atmosphere
- The simulations predicted regional increases, decreases and unchanged yields of dryland corn resulting from two future climate change scenarios
- Increases were predicted for future production of dryland corn in the Lakes, Corn Belt and Northeast regions of the U.S. Increases in irrigated corn yields are predicted in almost all regions of the country
- Soybean yields are anticipated to decrease in the Northern and Southern Plains, the Corn Belt, Delta, Appalachian, and Southeast regions. Soybean yields in the Lakes and Northeast regions should increase
- Winter wheat exhibited consistent trends of yield increase under the scenarios of climate change across the U.S.
- Evapotranspiration in dryland corn is expected to increase in both scenarios of future climate in response to the warming projected by HadCM2 runs
- Water-use efficiency of dryland corn is predicted to decrease by 2 – 4 kg ha^{-1} mm^{-1} under climate change
- Surface runoff could decrease from baseline during the 2030 period and increase during the 2095 period
- Dryland corn growing in 2030 would experience more days with water stress than it does under current climate
- Corn production is likely to change significantly in 2030 and 2095 in the three currently most important producing regions of the country
- In 2030, corn production is expected to increase in the Corn Belt and Lakes regions and to decrease in the Northern Plains. The overall impact would be a decrease in national production
- Corn yield changes predicted for these three regions by the end of the 21st century could afford a moderate increase in national production
- National production of dryland winter wheat is likely to increase in both future periods.

References

Brown, R.A., and N.J. Rosenberg. 1997. Sensitivity of crop yield and water use to change in a range of climatic factors and CO_2 concentrations: A simulation study applying EPIC to the Central USA. Agric. Forest Meteor. 83:171-203.

Brown, R.A., N.J. Rosenberg. 1999. Climate change impacts on the potential productivity of corn and winter wheat in their primary United States growing regions. Climatic Change 41:73-107.

Brown, R.A., N.J. Rosenberg, C. Hays, W.E. Easterling III, and L. Mearns. 1999. Potential production and environmental effects of switchgrass and traditional crops under current and grennhouse-altered climate in the MINK region of the central United States (*submitted to Agriculture, Ecosystems and Environment*).

Easterling, W.E., N.J. Rosenberg, M.S. McKenney, C.A. Jones, P.T. Dyke, and J.R. Williams. 1992. Preparing the erosion productivity impact calculator (EPIC) model to simulate crop responses to climate change and the direct effects of CO_2. Agric. Forest Meteor. 59:17-34.

Haxeltine, A., and I.C. Prentice. 1996. BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability and competition among plant functional types. Global Biogeochemical Cycles 10:693-709.

Hulme, M., E.M. Barrow, N. Arnell, P.A. Harrison, T.E. Downing, and T.C. Johns. 1999. Relative impacts of human-induced climate change and natural climate variability. Nature 397:588-691.

Izaurralde, R.C., N.J. Rosenberg, R.A. Brown, D.M. Legler, M. Tiscareño-López, and R. Srinivasan. 1999. Modeled effects of moderate and strong Los Niños on crop productivity in North America. Agric. Forest Meteor. 94:259-268.

Karl, T.R., P.D. Jones, R.W. Knight, G. Kukla, N. Plummer, V. Razuvayev, K.P. Gallo, J. Lindseay, R.J. Charlson, and T.C. Peterson. 1993. A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. Bull. Am. Meteorol. Soc. 74:1007-1023.

Reek, T., S.R. Doty, and T.W. Owen. 1992. A deterministic approach to the validation of historical daily temperature and precipitation data from the cooperative network. Bull. Am. Meteor. Soc. 73:753-772.

Srinivasan, R., J. G. Arnold, R. S. Muttiah, C. Walker, and P. T. Dyke. 1993. Hydrologic Unit Model for the United States (HUMUS). p. 451-456. *In* S. Y. Wang (ed.) Advances in Hydroscience and Engineering. Center for Computational Hydroscience and Engineering, Univ. of Mississippi Press, Oxford, MS.

U.S. National Assessment Synthesis Team. 1998. U.S. National Assessment: Overview of National Assessment Scenario Strategy. (http://www.nacc.usgcrp.gov/scenarios/ strategy.html).

Williams, J.R. 1995. The EPIC model. p. 909–1000 *In* V.P. Singh (ed.) Computer models of watershed hydrology. Water Res. Public. Highlands Ranch, Colorado.

Appendices

Appendix A.2: EPIC simulated mean yields and standard deviation for corn under dryland management for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect.

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	---Mg/ha---									
101	3.9	0.5	5.2	0.5	5.7	0.4	5.0	0.4	5.6	0.4
102	3.4	0.3	4.2	0.6	4.6	0.6	4.0	0.5	4.4	0.5
103	4.2	0.3	4.9	0.5	5.2	0.6	5.1	0.4	5.5	0.4
104	4.2	0.3	5.3	0.5	5.8	0.5	5.2	0.4	5.6	0.4
105	3.1	0.6	3.2	0.8	3.9	0.7	3.3	0.6	3.8	0.5
106	4.1	0.3	5.5	0.6	5.9	0.6	5.5	0.2	5.9	0.3
107	3.7	0.4	4.1	1.3	4.9	1.2	4.1	1.1	4.8	1.0
108	4.8	0.4	5.1	1.3	5.9	1.2	4.8	0.7	5.7	0.5
109	3.5	0.5	3.7	0.9	4.5	0.8	4.0	0.8	4.7	0.7
110	4.1	0.3	4.5	1.0	5.2	1.0	4.6	1.0	5.2	0.8
111	4.5	0.4	4.8	1.4	5.4	1.3	5.4	0.7	6.0	0.7
201	4.1	0.6	5.7	0.6	6.2	0.6	5.8	0.3	6.3	0.4
202	3.5	0.3	4.5	0.9	5.1	0.9	4.6	0.5	5.1	0.4
203	3.8	0.5	4.3	1.1	4.8	1.0	4.0	1.1	4.6	1.1
204	5.9	0.4	6.8	1.0	7.3	1.1	6.7	0.6	7.2	0.6
205	5.5	0.8	6.4	1.0	6.9	1.0	6.6	0.6	7.0	0.6
206	3.9	0.8	3.6	1.0	4.3	1.1	3.2	0.9	3.9	0.9
207	3.7	0.7	4.0	0.9	4.8	1.0	4.6	1.0	5.3	1.1
208	7.4	1.1	8.0	0.9	8.7	0.8	7.2	1.6	8.1	1.1
301	5.1	1.5	5.3	1.1	6.1	1.1	5.1	1.0	5.8	1.0
302	4.3	1.0	4.1	1.0	4.8	1.1	3.6	0.9	4.3	0.9
303	4.8	0.6	4.6	1.2	5.3	1.3	4.3	0.6	5.0	0.6
304	4.5	0.4	4.0	1.0	4.6	1.1	4.3	0.6	4.9	0.7
305	5.9	0.6	5.3	1.1	6.2	1.1	5.6	1.2	6.4	1.2
306	4.9	1.6	4.6	1.3	5.4	1.4	5.0	1.0	5.8	1.0
307	5.1	0.6	4.3	1.3	5.0	1.2	4.4	1.3	5.1	1.4
308	6.0	0.4	5.4	1.2	6.2	1.1	4.6	1.2	5.3	1.3
309	5.2	0.9	3.6	1.3	4.3	1.3	2.2	1.0	2.8	1.2
310	7.5	1.0	6.6	1.2	7.5	1.0	5.0	1.6	5.9	1.5
311	5.1	0.4	4.2	1.1	4.9	1.1	3.8	1.3	4.4	1.4
312	5.1	0.7	4.2	1.4	4.8	1.5	3.4	1.5	3.9	1.6
313	4.3	0.5	3.2	1.1	3.9	1.2	3.1	1.3	3.7	1.4
314	5.2	1.2	4.8	1.5	5.6	1.6	5.1	1.4	5.9	1.5
315	8.4	0.5	9.5	1.2	10.3	1.2	9.3	1.2	10.0	1.2
316	4.2	2.4	4.9	1.6	5.9	1.6	5.3	1.6	6.1	1.7
317	7.9	0.5	7.2	2.0	8.5	1.6	6.6	2.4	7.6	1.9
318	6.7	0.5	5.5	2.4	6.5	2.6	5.9	2.7	6.7	2.7
401	3.2	1.2	3.8	1.7	4.3	1.9	5.4	1.0	5.9	1.1
402	2.5	1.0	3.7	1.2	4.2	1.3	5.1	0.9	5.8	0.8
403	4.0	0.9	4.7	1.2	5.3	1.3	6.0	0.6	6.7	0.5
404	5.5	0.3	5.7	0.9	6.2	0.9	6.2	0.4	6.7	0.4
405	5.4	0.3	6.2	0.8	6.8	0.8	6.3	0.5	6.9	0.6
406	3.8	2.0	5.0	1.1	5.8	0.9	5.4	0.7	6.2	0.6
407	4.6	0.9	5.2	1.1	6.0	1.0	5.9	0.8	6.7	0.7
408	4.8	1.6	5.8	0.9	6.5	0.8	6.1	0.4	6.8	0.4
409	5.5	0.3	6.0	0.7	6.7	0.7	6.0	0.4	6.6	0.4
410	5.6	0.5	6.0	1.2	6.6	1.2	6.0	0.8	6.6	0.8
411	6.3	0.4	6.7	0.9	7.2	0.9	6.7	0.7	7.2	0.7
412	4.6	1.4	0.5	0.5	0.6	0.6	1.4	1.3	1.5	1.5
413	5.2	0.3	5.6	0.9	6.1	0.8	5.7	0.4	6.2	0.4
414	4.6	0.3	5.0	1.0	5.6	0.9	5.2	0.4	5.9	0.4
415	4.3	0.7	5.7	0.7	6.1	0.7	5.7	0.4	6.1	0.4
501	2.5	0.9	5.2	1.7	5.7	1.8	6.1	0.7	6.7	0.7
502	6.0	0.6	7.0	1.0	7.6	0.9	7.3	0.7	7.9	0.6
503	6.2	0.4	6.4	1.2	7.2	1.2	6.7	0.8	7.4	0.8
504	5.9	0.4	6.2	1.2	6.9	1.1	6.3	0.9	6.9	0.8
505	6.9	0.5	6.5	0.9	7.2	0.9	6.7	0.6	7.4	0.6
506	5.8	0.5	6.2	1.0	6.9	0.9	6.5	0.8	7.1	0.9
507	8.8	0.5	8.0	1.6	9.0	1.4	8.3	1.2	9.1	1.1
508	6.8	0.4	7.3	0.8	8.0	0.8	7.3	0.8	7.9	0.8
509	5.9	0.6	5.9	1.2	6.5	1.2	6.2	0.8	6.8	0.8
510	6.5	3.0	7.0	1.4	7.7	1.4	7.5	1.1	8.2	1.1
511	6.7	0.6	6.0	1.3	6.7	1.2	6.6	1.2	7.2	1.2
512	6.7	0.4	6.5	1.2	7.1	1.2	6.6	0.9	7.0	1.0
513	7.3	0.7	6.5	1.6	7.3	1.5	7.2	1.1	7.8	1.1
514	7.0	0.9	5.8	1.8	6.6	1.7	6.5	1.4	7.2	1.4
601	6.5	1.5	6.6	1.4	7.5	1.3	7.1	1.2	7.9	1.1
602	6.0	0.4	5.8	1.7	6.6	1.7	6.6	1.6	7.3	1.6
603	8.1	0.5	8.9	1.5	9.8	1.4	8.9	1.4	9.6	1.3
604	6.3	2.1	6.5	1.5	7.3	1.4	7.3	1.4	8.0	1.4
701	5.5	0.7	5.7	1.3	6.3	1.3	6.7	0.3	7.4	0.3
702	5.7	0.4	6.2	1.5	7.0	1.1	6.2	0.8	6.9	0.8
703	5.2	0.4	5.0	1.2	5.6	1.2	6.0	0.4	6.7	0.4
704	5.7	0.3	6.6	0.9	7.1	1.0	6.9	0.4	7.5	0.5
705	3.9	1.1	5.2	1.8	6.0	1.6	6.4	0.5	7.1	0.3
706	5.9	0.3	6.4	0.8	7.0	0.8	6.8	0.6	7.3	0.7
707	5.2	0.5	5.0	2.0	5.8	1.8	6.1	0.8	6.8	0.5
708	5.8	0.4	6.4	0.9	7.0	0.9	6.6	0.6	7.1	0.7
709	4.3	1.9	6.1	0.8	6.6	0.9	6.4	0.6	6.8	0.6
710	5.9	0.3	6.3	1.5	7.1	1.1	6.7	0.9	7.2	0.9
711	5.4	0.7	5.3	1.7	6.2	1.6	5.7	1.4	6.3	1.5
712	5.2	0.4	6.1	1.1	6.6	1.1	6.3	0.9	6.8	1.0
713	6.1	0.4	6.7	1.1	7.3	1.1	6.8	1.1	7.4	1.2
714	4.7	0.8	4.5	1.8	5.3	1.6	5.0	1.3	5.7	1.3
801	6.4	0.7	5.6	1.8	6.3	1.7	6.2	1.4	6.7	1.4
802	6.6	1.4	4.9	2.3	6.1	1.9	5.1	2.1	5.3	2.1
803	4.0	2.2	4.2	1.4	4.1	1.3	2.5	1.7	2.3	1.7
804	5.2	2.3	4.8	3.1	6.1	3.0	6.2	1.8	6.6	1.6
805	4.6	2.3	5.5	2.5	6.7	2.2	6.0	1.5	5.7	1.9
806	7.4	0.5	6.4	1.8	7.5	1.8	6.8	1.5	7.6	1.3

Appendix A.2 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	--Mg/ha--									
807	5.6	0.3	6.0	1.3	6.7	1.4	5.5	1.5	6.2	1.5
808	7.2	1.9	7.6	1.0	8.2	0.9	6.5	1.3	7.0	1.3
809	6.2	0.4	7.7	0.8	8.2	0.8	6.6	1.1	7.2	1.1
901	4.1	1.5	1.5	1.2	2.4	1.6	2.2	1.8	3.5	1.9
902	5.2	0.3	3.3	2.0	4.2	2.3	4.0	1.8	5.3	1.3
903	3.0	1.4	4.0	1.6	4.9	1.7	5.8	1.1	6.6	1.1
1001	0.9	0.8	0.6	0.8	0.7	1.0	2.4	0.8	2.9	0.8
1002	0.4	0.4	0.4	0.3	0.7	0.5	0.4	0.4	0.6	0.9
1003	1.4	1.2	0.5	0.4	0.9	0.8	0.3	0.5	0.6	0.9
1004	1.7	1.6	1.0	0.9	1.6	1.4	1.0	1.1	1.6	1.4
1005	1.5	1.5	0.6	0.6	1.1	1.1	0.7	0.8	1.1	1.2
1006	1.6	1.4	1.4	1.0	2.2	1.5	1.1	1.4	1.6	1.6
1007	2.0	0.7	3.2	1.0	3.8	1.2	4.8	0.4	5.5	0.4
1008	0.6	0.8	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
1009	2.0	1.6	0.5	0.6	1.0	1.4	0.6	0.7	1.0	1.2
1010	1.1	1.3	0.4	0.4	0.9	0.8	0.8	0.9	1.2	1.4
1011	3.0	1.7	1.9	1.5	3.0	1.9	1.8	2.0	2.6	2.3
1012	3.4	1.5	2.0	1.2	3.4	1.7	1.9	1.7	3.1	2.3
1013	3.5	1.7	1.9	1.6	2.8	2.1	1.3	1.1	2.0	1.6
1014	2.8	1.8	2.0	1.2	3.2	1.9	1.0	0.9	1.7	1.4
1015	2.4	1.8	2.1	1.5	3.3	2.3	1.5	1.3	2.4	1.9
1016	4.9	0.9	3.4	2.3	4.6	2.7	3.0	2.1	4.2	2.5
1017	5.6	0.6	4.7	2.5	5.8	2.5	5.6	1.9	6.6	1.0
1018	2.2	1.5	0.4	0.2	0.7	0.6	0.5	0.5	1.0	1.1
1019	2.3	1.3	0.6	0.5	1.1	1.0	0.7	0.9	1.1	1.2
1020	5.9	0.4	5.5	1.9	6.6	1.4	6.0	1.1	6.7	1.0
1021	6.1	0.4	4.5	2.9	5.9	2.5	5.5	1.6	7.0	1.1
1022	5.7	0.5	4.2	3.1	5.3	3.0	5.3	2.3	6.6	1.9
1023	6.6	0.6	5.8	2.3	7.0	1.6	7.1	1.0	7.7	1.0
1024	6.0	1.5	6.8	1.3	7.4	1.2	6.8	1.2	7.3	1.3
1025	5.3	0.5	2.9	2.3	4.6	2.3	4.0	2.0	5.4	2.1
1026	4.1	2.2	1.6	2.2	2.3	2.6	2.6	1.9	3.8	2.2
1027	6.2	0.6	4.8	2.9	5.8	2.7	5.7	1.6	6.6	1.3
1028	6.0	0.8	6.7	1.4	7.4	1.3	6.8	1.3	7.2	1.3
1029	7.0	0.5	6.7	1.3	7.5	1.3	6.9	1.3	7.4	1.3
1030	7.1	0.4	7.2	1.3	7.8	1.3	7.0	1.3	7.5	1.3
1101	6.1	1.4	4.4	1.9	5.3	1.8	5.7	2.1	6.6	2.0
1102	0.9	0.8	0.5	0.5	0.8	0.8	0.3	0.3	0.5	0.5
1103	5.2	1.5	2.3	2.3	3.7	2.4	3.8	2.2	5.1	2.1
1104	2.5	2.0	0.9	0.9	1.4	1.2	1.2	0.9	1.9	1.3
1105	5.7	1.3	3.7	2.4	5.4	2.2	5.2	1.6	6.3	1.5
1106	6.0	0.9	4.8	2.1	6.2	1.7	5.6	1.6	6.4	1.5
1107	7.2	0.6	6.5	1.6	7.3	1.6	6.4	1.4	6.9	1.4
1108	0.2	0.4	0.8	1.0	1.3	1.3	1.0	0.9	1.4	1.2
1109	3.5	2.7	2.1	1.7	3.6	2.4	2.3	2.1	3.8	2.6
1110	4.3	2.5	2.8	2.1	4.2	2.5	3.9	1.7	5.3	1.7
1111	7.5	0.6	6.1	2.1	7.0	2.0	6.6	1.3	7.1	1.4
1112	4.3	2.8	2.7	2.3	3.7	2.8	3.1	2.0	4.4	2.3

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 – 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	--Mg/ha--									
1113	6.6	0.9	5.4	2.0	6.9	1.6	6.3	1.2	7.1	1.1
1114	6.8	1.1	7.2	1.4	8.0	1.3	6.4	1.9	6.8	2.1
1201	7.8	1.5	8.2	1.5	9.1	1.3	7.2	1.4	7.4	1.3
1202	8.9	0.9	6.9	3.1	8.3	2.5	7.4	1.7	8.2	1.5
1203	7.6	1.5	6.5	2.0	8.3	1.6	7.1	1.7	7.4	1.4
1204	9.0	0.5	8.4	1.8	9.4	1.4	6.8	2.1	8.0	1.6
1205	3.7	3.1	2.7	2.3	4.1	3.1	2.5	2.1	3.6	2.6
1206	3.6	2.7	3.8	2.9	5.7	3.0	4.6	2.0	6.2	1.8
1207	7.8	1.9	6.0	3.1	8.0	2.8	6.1	2.3	7.4	2.4
1208	3.7	3.0	2.5	2.3	3.9	3.1	2.2	1.8	3.4	2.4
1209	7.3	2.6	5.6	3.3	7.4	3.2	5.6	2.5	7.5	1.9
1210	7.5	2.3	5.7	2.8	7.5	3.2	3.7	2.2	5.5	2.3
1211	5.9	3.1	2.5	2.3	3.6	3.3	1.4	1.9	2.2	2.5
1301	0.9	0.6	0.2	0.2	0.3	0.3	0.4	0.7	0.6	0.9
1302	0.4	0.5	0.2	0.3	0.4	0.4	0.2	0.2	0.3	0.3
1303	1.8	1.3	0.3	0.6	0.5	0.8	0.1	0.1	0.2	0.1
1304	1.9	2.2	1.7	1.7	2.6	2.3	2.3	1.9	3.3	2.8
1305	0.9	1.2	3.3	2.0	4.5	2.0	3.9	2.0	5.5	1.9
1306	2.2	1.8	0.3	0.3	0.4	0.5	0.3	0.4	0.5	0.5
1307	0.7	0.9	0.3	0.5	0.5	0.6	0.6	0.9	0.8	1.1
1308	4.9	2.8	2.8	2.8	4.4	3.3	1.5	1.7	2.8	2.4
1309	4.9	2.7	3.0	2.7	4.8	3.0	0.7	0.9	1.6	1.8
1401	0.5	0.4	0.3	0.3	0.4	0.4	1.4	0.6	2.0	0.8
1402	0.4	0.3	0.3	0.1	0.6	0.4	2.4	1.1	3.5	1.4
1403	2.6	1.3	0.2	0.2	0.4	0.3	0.5	0.5	1.0	1.1
1404	0.2	0.3	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
1405	0.9	0.8	0.8	0.5	1.3	0.8	1.6	1.0	2.9	1.5
1406	0.4	0.6	0.2	0.3	0.3	0.5	0.2	0.3	0.2	0.4
1407	0.3	0.3	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1
1408	0.6	0.4	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.1
1501	0.2	0.5	0.0	0.0	0.0	0.0	0.3	0.5	0.8	1.2
1502	0.4	0.4	0.2	0.3	0.2	0.4	0.0	0.0	0.1	0.1
1503	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
1504	2.4	1.5	0.4	0.5	0.7	0.8	0.2	0.6	0.4	1.0
1505	0.4	0.7	0.3	0.4	0.8	1.3	0.8	1.0	1.9	1.9
1506	1.5	1.5	1.9	2.1	3.4	2.5	1.2	1.1	3.0	1.4
1507	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
1508	0.5	1.0	0.2	0.1	0.5	0.5	0.5	0.3	1.7	1.1
1601	1.2	1.2	0.2	0.2	0.3	0.3	0.5	0.6	0.7	0.7
1602	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
1603	0.4	0.5	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
1604	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
1605	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
1606	0.2	0.3	0.0	0.1	0.1	0.2	0.2	0.6	0.3	0.8
1701	4.3	0.5	2.1	0.5	3.2	0.9	2.2	1.9	3.8	1.6
1702	0.3	0.3	0.1	0.2	0.2	0.3	0.0	0.1	0.1	0.1
1703	0.0	0.1	0.3	0.3	0.4	0.5	0.1	0.1	0.2	0.2
1704	0.2	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0

Appendix A.2 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$
	---Mg/ha---									
1705	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.2
1706	1.3	0.6	0.4	0.6	0.4	0.7	2.5	1.0	3.0	1.3
1707	1.8	1.4	0.1	0.1	0.3	0.3	0.2	0.3	0.6	0.7
1708	4.5	1.6	3.2	1.2	3.8	1.5	6.1	1.1	7.2	0.8
1709	5.8	1.3	5.4	0.9	6.8	0.7	6.5	0.9	7.4	0.8
1710	5.5	1.0	5.0	0.7	6.5	0.7	6.5	0.7	7.5	0.7
1711	3.0	0.9	2.9	1.5	3.6	1.5	4.3	2.7	5.5	2.7
1712	0.2	0.4	0.1	0.1	0.1	0.2	0.0	0.1	0.1	0.1
1801	0.4	0.6	0.2	0.1	0.3	0.2	0.7	0.8	0.9	1.1
1802	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
1803	0.1	0.5	0.1	0.1	0.1	0.1	0.9	0.9	2.0	1.9
1804	0.3	0.3	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.0
1805	1.0	0.9	0.1	0.0	0.2	0.1	0.1	0.0	0.2	0.1
1806	0.2	0.5	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0
1807	1.5	2.3	1.9	1.7	3.2	2.4	4.8	1.2	6.2	0.8
1808	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.3
1809	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1810	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix A.3: EPIC simulated mean yields and standard deviation for soybean under dryland management for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect.

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	----------Mg/ha----------									
101	0.5	0.1	0.9	0.3	1.0	0.3	1.3	0.3	1.5	0.4
102	0.6	0.1	0.7	0.2	0.9	0.3	1.2	0.2	1.4	0.2
103	1.0	0.3	0.7	0.3	0.8	0.3	1.1	0.4	1.3	0.5
104	1.4	0.3	0.8	0.3	0.9	0.4	1.3	0.5	1.5	0.5
105	0.7	0.2	1.2	0.2	1.4	0.2	1.3	0.2	1.6	0.2
106	1.5	0.2	1.5	0.3	1.8	0.4	1.9	0.2	2.2	0.2
107	1.5	0.2	1.3	0.3	1.6	0.3	1.7	0.3	2.0	0.3
108	1.2	0.3	1.3	0.3	1.6	0.3	1.7	0.3	2.0	0.3
109	1.3	0.2	1.1	0.4	1.4	0.4	1.1	0.3	1.4	0.3
110	1.3	0.2	1.5	0.4	1.8	0.4	1.5	0.2	1.8	0.2
111	1.0	0.3	0.9	0.2	1.0	0.3	1.4	0.4	1.7	0.5
201	0.6	0.2	1.7	0.2	2.0	0.3	1.8	0.2	2.1	0.3
202	1.3	0.1	1.5	0.3	1.8	0.3	1.5	0.2	1.8	0.2
203	1.2	0.2	1.4	0.4	1.7	0.4	1.4	0.3	1.6	0.3
204	1.9	0.2	2.1	0.4	2.5	0.5	2.0	0.3	2.3	0.4
205	1.3	0.4	1.7	0.5	1.9	0.6	1.9	0.2	2.2	0.3
206	1.4	0.2	1.3	0.3	1.6	0.4	1.0	0.3	1.3	0.3
207	1.2	0.2	1.3	0.3	1.6	0.4	1.3	0.3	1.6	0.4
208	2.3	0.4	2.2	0.4	2.6	0.4	2.0	0.5	2.4	0.5
301	1.6	0.3	1.5	0.3	1.9	0.3	1.4	0.3	1.7	0.4
302	1.2	0.2	1.2	0.3	1.5	0.4	1.0	0.3	1.3	0.3
303	1.3	0.2	1.3	0.3	1.6	0.4	1.2	0.2	1.4	0.2
304	1.2	0.1	1.2	0.3	1.4	0.3	1.1	0.1	1.3	0.2
305	1.5	0.2	1.3	0.3	1.6	0.4	1.3	0.3	1.6	0.4
306	1.5	0.2	1.2	0.3	1.5	0.4	1.2	0.2	1.5	0.3
307	1.4	0.2	1.1	0.4	1.4	0.4	1.2	0.3	1.5	0.3
308	1.8	0.1	1.6	0.4	1.9	0.4	1.4	0.3	1.7	0.4
309	1.1	0.5	0.9	0.4	1.0	0.5	0.7	0.3	0.8	0.4
310	2.3	0.1	2.0	0.3	2.4	0.3	1.6	0.4	1.9	0.4
311	1.5	0.2	1.3	0.3	1.6	0.4	1.2	0.4	1.5	0.4
312	1.5	0.1	1.3	0.4	1.6	0.5	1.1	0.3	1.3	0.4
313	1.2	0.2	0.9	0.3	1.1	0.3	1.0	0.3	1.2	0.3
314	1.3	0.1	1.2	0.3	1.4	0.3	1.1	0.4	1.4	0.4
315	2.1	0.1	2.0	0.5	2.4	0.5	2.0	0.5	2.4	0.5
316	1.4	0.4	1.1	0.3	1.4	0.3	1.2	0.4	1.4	0.4
317	2.2	0.1	1.8	0.5	2.2	0.5	1.7	0.5	2.0	0.5
318	1.4	0.1	1.2	0.3	1.5	0.4	1.3	0.3	1.5	0.4
401	0.8	0.3	1.0	0.5	1.2	0.6	1.4	0.4	1.6	0.4
402	0.6	0.3	0.9	0.4	1.1	0.5	1.4	0.3	1.7	0.3
403	0.9	0.3	1.2	0.4	1.5	0.5	1.8	0.2	2.1	0.3
404	1.8	0.2	1.7	0.5	2.1	0.6	1.9	0.3	2.2	0.3
405	1.7	0.1	1.8	0.3	2.1	0.4	1.7	0.4	2.0	0.4
406	1.2	0.5	1.5	0.3	1.8	0.4	1.7	0.3	2.0	0.3
407	1.3	0.3	1.5	0.4	1.8	0.4	1.9	0.2	2.2	0.2
408	1.5	0.4	1.8	0.3	2.1	0.3	1.7	0.2	2.1	0.3
409	1.8	0.1	1.8	0.3	2.2	0.3	1.6	0.3	1.9	0.4
410	1.9	0.2	1.9	0.4	2.3	0.5	1.8	0.4	2.1	0.4
411	1.9	0.2	1.9	0.5	2.2	0.5	1.8	0.3	2.1	0.4
412	1.5	0.3	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
413	1.8	0.2	1.5	0.5	1.8	0.5	1.8	0.2	2.1	0.2
414	1.6	0.2	1.7	0.4	2.0	0.4	1.7	0.3	2.0	0.3
415	1.1	0.3	1.3	0.4	1.5	0.5	1.6	0.3	1.8	0.4
501	0.6	0.2	1.2	0.4	1.5	0.5	1.5	0.4	1.8	0.4
502	2.0	0.3	2.3	0.5	2.7	0.6	2.4	0.3	2.8	0.3
503	2.2	0.1	2.2	0.4	2.6	0.5	2.2	0.3	2.6	0.4
504	1.8	0.2	1.7	0.4	2.1	0.5	1.7	0.3	2.0	0.4
505	2.3	0.3	2.1	0.4	2.5	0.4	2.1	0.3	2.5	0.3
506	2.0	0.2	2.0	0.3	2.3	0.4	1.9	0.4	2.2	0.4
507	2.5	0.3	2.2	0.5	2.6	0.5	2.1	0.5	2.5	0.5
508	2.3	0.2	2.3	0.4	2.7	0.4	2.3	0.4	2.7	0.4
509	2.0	0.2	1.9	0.4	2.2	0.4	1.9	0.3	2.2	0.3
510	2.0	0.5	1.8	0.5	2.2	0.6	1.9	0.4	2.2	0.4
511	2.0	0.2	1.6	0.4	1.9	0.4	1.6	0.3	1.8	0.3
512	2.3	0.1	2.0	0.5	2.3	0.6	2.0	0.4	2.3	0.4
513	2.1	0.2	1.8	0.4	2.1	0.4	1.7	0.3	2.1	0.3
514	2.1	0.3	1.6	0.4	1.9	0.5	1.6	0.4	1.9	0.4
601	2.0	0.3	1.9	0.4	2.2	0.4	1.9	0.4	2.2	0.5
602	1.8	0.2	1.6	0.4	1.9	0.5	1.7	0.4	2.0	0.5
603	2.2	0.1	1.9	0.4	2.3	0.4	2.0	0.5	2.3	0.5
604	1.9	0.5	1.8	0.4	2.1	0.4	1.8	0.5	2.1	0.5
701	1.6	0.3	1.6	0.6	1.9	0.6	2.0	0.2	2.4	0.2
702	1.8	0.2	1.9	0.5	2.3	0.5	1.9	0.3	2.2	0.3
703	1.6	0.3	1.4	0.5	1.7	0.6	1.7	0.2	2.0	0.3
704	1.9	0.1	1.9	0.5	2.2	0.6	2.1	0.2	2.4	0.2
705	0.9	0.3	1.4	0.6	1.7	0.7	1.8	0.2	2.2	0.2
706	1.9	0.2	1.7	0.4	2.0	0.5	1.8	0.3	2.1	0.4
707	1.5	0.3	1.4	0.5	1.8	0.6	1.8	0.3	2.1	0.3
708	1.8	0.1	1.7	0.4	2.0	0.5	1.8	0.4	2.1	0.4
709	1.5	0.5	1.8	0.4	2.1	0.5	1.9	0.4	2.2	0.4
710	1.9	0.1	1.6	0.5	1.9	0.5	1.7	0.3	2.0	0.4
711	1.8	0.3	1.4	0.5	1.7	0.5	1.5	0.5	1.7	0.6
712	1.7	0.1	1.8	0.5	2.1	0.5	1.8	0.5	2.1	0.5
713	2.1	0.2	1.8	0.4	2.2	0.5	1.9	0.5	2.2	0.6
714	1.8	0.3	1.5	0.5	1.8	0.5	1.6	0.5	1.9	0.6
801	1.8	0.2	1.5	0.5	1.8	0.5	1.5	0.5	1.8	0.5
802	2.0	0.4	1.5	0.6	1.8	0.6	1.3	0.5	1.4	0.6
803	1.5	0.6	1.3	0.3	1.5	0.3	0.8	0.6	0.8	0.6
804	1.7	0.5	1.4	0.7	1.8	0.8	1.3	0.5	1.4	0.5
805	1.5	0.6	1.4	0.5	1.8	0.6	1.1	0.4	1.1	0.5
806	1.8	0.1	1.4	0.4	1.7	0.5	1.5	0.3	1.7	0.4

Appendix A.3 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	------------------Mg/ha------------------									
807	1.4	0.1	1.5	0.3	1.8	0.4	1.3	0.3	1.6	0.3
808	1.9	0.2	1.8	0.4	2.1	0.4	1.4	0.2	1.6	0.3
809	1.5	0.1	1.8	0.2	2.0	0.3	1.4	0.3	1.6	0.3
901	1.2	0.4	0.7	0.3	0.9	0.4	1.0	0.5	1.3	0.6
902	1.7	0.3	1.0	0.5	1.4	0.6	1.4	0.5	1.8	0.5
903	0.8	0.3	1.2	0.5	1.5	0.6	1.6	0.4	2.0	0.5
1001	0.3	0.2	0.2	0.2	0.2	0.2	0.6	0.2	0.7	0.3
1002	0.3	0.1	0.4	0.1	0.5	0.2	0.3	0.2	0.5	0.2
1003	0.5	0.2	0.5	0.2	0.6	0.2	0.4	0.2	0.6	0.3
1004	0.7	0.4	0.6	0.2	0.8	0.3	0.5	0.2	0.7	0.3
1005	0.6	0.3	0.5	0.2	0.7	0.2	0.5	0.3	0.6	0.3
1006	0.7	0.4	0.7	0.3	1.0	0.5	0.7	0.4	0.9	0.5
1007	0.5	0.2	0.8	0.3	1.0	0.4	1.6	0.3	2.0	0.4
1008	0.4	0.2	0.2	0.1	0.2	0.0	0.1	0.1	0.2	0.1
1009	0.7	0.3	0.5	0.2	0.6	0.3	0.4	0.2	0.6	0.2
1010	0.6	0.4	0.5	0.3	0.7	0.3	0.5	0.3	0.6	0.3
1011	1.0	0.4	0.8	0.4	1.1	0.5	0.8	0.5	1.1	0.6
1012	1.0	0.3	0.8	0.2	1.1	0.3	0.9	0.4	1.3	0.5
1013	1.1	0.5	0.8	0.4	1.0	0.5	0.6	0.3	0.8	0.4
1014	1.0	0.5	0.8	0.4	1.1	0.5	0.6	0.3	0.9	0.4
1015	1.1	0.4	0.9	0.3	1.2	0.4	0.8	0.3	1.1	0.4
1016	1.5	0.4	1.1	0.5	1.5	0.7	1.2	0.5	1.6	0.6
1017	2.0	0.2	1.6	0.7	2.0	0.8	1.8	0.6	2.3	0.5
1018	0.8	0.2	0.5	0.1	0.8	0.1	0.5	0.2	0.7	0.2
1019	0.7	0.2	0.4	0.1	0.6	0.2	0.4	0.2	0.5	0.3
1020	2.0	0.2	1.8	0.5	2.2	0.6	1.7	0.3	2.1	0.3
1021	2.0	0.2	1.6	0.6	2.1	0.7	1.6	0.5	2.2	0.5
1022	1.8	0.3	1.4	0.8	1.8	0.9	1.6	0.6	2.0	0.7
1023	2.1	0.3	1.7	0.7	2.1	0.7	1.9	0.3	2.3	0.4
1024	2.0	0.3	1.9	0.4	2.2	0.5	1.8	0.5	2.1	0.6
1025	1.7	0.3	1.2	0.4	1.7	0.5	1.2	0.4	1.6	0.5
1026	1.4	0.5	0.8	0.3	1.1	0.4	0.8	0.3	1.1	0.4
1027	2.1	0.2	1.4	0.7	1.8	0.8	1.5	0.4	1.8	0.4
1028	2.0	0.3	1.8	0.6	2.1	0.6	1.7	0.5	2.0	0.5
1029	2.2	0.2	1.8	0.4	2.1	0.4	1.7	0.5	2.0	0.6
1030	2.3	0.2	1.9	0.4	2.2	0.5	1.7	0.5	2.0	0.6
1101	1.9	0.3	1.3	0.4	1.6	0.4	1.5	0.6	1.8	0.7
1102	0.6	0.2	0.3	0.1	0.4	0.2	0.3	0.1	0.4	0.2
1103	1.6	0.5	1.0	0.5	1.3	0.5	0.9	0.3	1.3	0.4
1104	1.0	0.4	0.5	0.2	0.7	0.3	0.4	0.2	0.6	0.2
1105	1.4	0.4	1.0	0.6	1.3	0.7	0.9	0.4	1.2	0.4
1106	1.5	0.3	1.2	0.6	1.5	0.7	1.0	0.3	1.2	0.4
1107	2.2	0.2	1.6	0.3	1.9	0.4	1.4	0.4	1.7	0.5
1108	0.1	0.2	0.6	0.3	0.8	0.4	0.6	0.5	0.9	0.7
1109	1.5	0.4	0.9	0.4	1.3	0.6	0.9	0.4	1.2	0.5
1110	1.4	0.5	0.9	0.5	1.2	0.6	0.9	0.4	1.3	0.4
1111	2.1	0.2	1.6	0.6	2.0	0.7	1.5	0.5	1.8	0.5
1112	1.5	0.6	0.6	0.2	0.8	0.3	0.6	0.3	0.9	0.4

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	------------------Mg/ha------------------									
1113	1.6	0.3	1.1	0.5	1.4	0.6	1.0	0.4	1.2	0.4
1114	1.9	0.2	1.5	0.5	1.8	0.5	1.2	0.3	1.4	0.3
1201	2.0	0.2	1.6	0.3	2.0	0.4	1.2	0.3	1.4	0.3
1202	2.0	0.2	1.5	0.5	1.8	0.6	1.3	0.4	1.5	0.4
1203	2.0	0.3	1.5	0.5	1.9	0.5	1.2	0.3	1.4	0.3
1204	1.9	0.2	1.5	0.5	1.9	0.5	1.1	0.3	1.3	0.4
1205	1.5	0.6	0.8	0.4	1.1	0.5	0.8	0.4	1.1	0.5
1206	1.2	0.5	1.2	0.5	1.5	0.5	1.2	0.4	1.5	0.4
1207	2.0	0.4	1.3	0.5	1.7	0.5	1.3	0.5	1.6	0.5
1208	1.5	0.6	0.8	0.4	1.1	0.6	0.8	0.4	1.1	0.4
1209	1.9	0.5	1.5	0.5	2.0	0.6	1.4	0.5	1.8	0.5
1210	1.9	0.4	1.3	0.5	1.7	0.6	1.1	0.5	1.4	0.6
1211	1.5	0.7	0.9	0.4	1.1	0.6	0.6	0.3	0.9	0.4
1301	0.2	0.1	0.2	0.1	0.3	0.1	0.3	0.2	0.5	0.2
1302	0.3	0.2	0.3	0.2	0.4	0.2	0.4	0.3	0.5	0.4
1303	1.0	0.5	0.3	0.2	0.4	0.3	0.3	0.3	0.4	0.4
1304	1.1	0.7	1.0	0.5	1.3	0.7	1.0	0.4	1.4	0.5
1305	0.7	0.5	1.1	0.3	1.4	0.4	1.7	0.4	2.3	0.6
1306	1.0	0.6	0.4	0.3	0.6	0.4	0.4	0.3	0.5	0.4
1307	0.5	0.5	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2
1308	1.3	0.6	0.9	0.5	1.3	0.6	0.8	0.4	1.0	0.5
1309	1.5	0.7	1.1	0.7	1.4	0.7	0.6	0.4	0.8	0.4
1401	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.2	0.6	0.2
1402	0.0	0.1	0.1	0.1	0.1	0.1	0.4	0.2	0.5	0.3
1403	0.3	0.2	0.4	0.2	0.6	0.2	0.7	0.4	1.0	0.5
1404	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
1405	0.3	0.1	0.5	0.1	0.6	0.2	0.7	0.2	1.0	0.3
1406	0.3	0.2	0.3	0.1	0.4	0.1	0.5	0.2	0.7	0.3
1407	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1
1408	0.5	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2
1501	0.2	0.2	0.2	0.1	0.3	0.1	0.4	0.2	0.6	0.3
1502	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.2
1503	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1
1504	1.2	0.5	0.4	0.2	0.6	0.3	0.4	0.3	0.5	0.4
1505	1.1	0.6	0.5	0.3	0.7	0.4	0.4	0.1	0.6	0.2
1506	1.3	0.4	1.4	0.6	2.0	0.7	1.1	0.4	1.5	0.5
1507	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1
1508	1.0	0.6	0.6	0.3	0.8	0.4	0.4	0.2	0.7	0.2
1601	0.6	0.1	0.2	0.1	0.4	0.1	0.5	0.2	0.7	0.3
1602	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1
1603	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.3	0.2
1604	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3	0.2
1605	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1
1606	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1701	1.2	0.3	0.7	0.2	0.9	0.4	0.9	0.3	1.3	0.4
1702	0.6	0.3	0.3	0.1	0.5	0.2	0.3	0.1	0.5	0.1
1703	0.5	0.1	0.6	0.2	0.8	0.2	0.5	0.1	0.8	0.1
1704	0.3	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.3	0.2

Appendix A.3 (cont.)

USGS Four Digit Basin	Baseline [CO_2] = 365		Hadley (2025-2034) 365		Hadley (2025-2034) 560		Hadley (2090 - 2099) 365		Hadley (2090 - 2099) 560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	----------Mg/ha----------									
1705	0.3	0.2	0.3	0.1	0.5	0.2	0.3	0.2	0.5	0.3
1706	0.8	0.3	0.5	0.4	0.6	0.5	1.4	0.5	1.7	0.6
1707	0.8	0.3	0.5	0.2	0.7	0.3	0.4	0.2	0.6	0.2
1708	1.6	0.4	1.4	0.3	1.7	0.4	1.9	0.2	2.3	0.2
1709	1.3	0.3	1.7	0.4	2.1	0.4	1.7	0.2	2.2	0.3
1710	0.8	0.2	1.6	0.2	2.1	0.2	1.6	0.2	2.1	0.2
1711	1.1	0.3	1.1	0.4	1.4	0.4	1.4	0.4	1.8	0.4
1712	0.3	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3	0.2
1801	0.5	0.1	0.3	0.1	0.5	0.1	0.5	0.2	0.7	0.3
1802	0.0	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.7	0.1
1803	0.3	0.3	0.2	0.1	0.3	0.2	0.4	0.2	0.6	0.3
1804	0.5	0.1	0.4	0.1	0.6	0.1	0.4	0.1	0.5	0.1
1805	0.9	0.2	0.6	0.2	0.8	0.2	0.5	0.1	0.8	0.1
1806	0.5	0.2	0.3	0.0	0.5	0.1	0.3	0.1	0.4	0.0
1807	0.7	0.5	0.7	0.2	1.0	0.3	0.9	0.1	1.3	0.1
1808	0.4	0.1	0.3	0.1	0.4	0.1	0.4	0.1	0.6	0.1
1809	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1810	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Appendix A.4: EPIC simulated mean yields and standard deviation for winter wheat under dryland management for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect.

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	---Mg/ha---									
101	3.1	0.4	3.9	0.6	4.6	0.7	4.1	0.5	4.8	0.6
102	2.4	0.3	3.0	0.5	3.6	0.6	3.1	0.3	3.8	0.3
103	3.2	0.3	4.0	0.7	4.7	0.8	4.3	0.4	5.0	0.4
104	3.2	0.3	4.2	0.6	5.0	0.7	4.5	0.4	5.2	0.4
105	2.4	0.3	3.0	0.4	3.7	0.4	3.1	0.6	3.9	0.7
106	3.2	0.3	4.6	0.7	5.4	0.8	4.9	0.6	5.6	0.6
107	2.5	0.3	3.3	0.4	4.0	0.5	3.3	0.3	4.1	0.4
108	3.1	0.4	4.0	0.5	4.8	0.5	4.2	0.5	5.0	0.5
109	3.4	0.3	4.8	0.6	5.5	0.7	6.0	0.6	7.0	0.7
110	2.6	0.3	3.7	0.7	4.5	0.8	4.8	0.5	5.8	0.6
111	2.2	0.3	2.8	0.3	3.5	0.4	3.0	0.5	3.7	0.5
201	2.5	0.3	2.7	0.3	3.4	0.3	2.8	0.4	3.5	0.5
202	2.4	0.3	3.4	0.6	4.1	0.7	3.9	0.4	4.7	0.5
203	2.1	0.3	3.4	0.4	4.1	0.5	4.1	0.6	4.9	0.6
204	2.3	0.4	3.0	0.5	3.7	0.6	3.6	0.5	4.5	0.6
205	3.0	0.4	3.6	0.9	4.2	1.0	4.3	0.5	5.2	0.6
206	2.5	0.5	3.2	0.5	4.1	0.6	4.0	0.4	5.0	0.4
207	3.4	0.3	4.3	0.7	5.1	0.8	4.6	0.7	5.4	0.8
208	2.4	0.5	2.7	0.4	3.4	0.5	3.4	0.4	4.2	0.6
301	2.8	0.7	3.3	0.8	4.1	0.9	4.1	0.5	5.0	0.6
302	3.0	0.7	3.5	0.7	4.3	0.8	3.9	0.4	4.8	0.5
303	4.2	0.7	5.4	0.5	6.4	0.6	5.5	0.6	6.5	0.7
304	2.6	0.6	3.0	0.5	3.8	0.6	3.4	0.4	4.2	0.5
305	3.1	0.6	3.3	0.6	4.1	0.7	3.7	0.5	4.6	0.6
306	2.7	0.9	3.1	0.4	3.9	0.4	3.7	0.4	4.6	0.6
307	3.1	0.5	3.2	0.3	4.0	0.5	3.7	0.4	4.5	0.6
308	3.4	0.7	2.7	0.8	3.5	0.9	2.6	0.5	3.4	0.6
309	2.5	0.8	1.8	0.5	2.4	0.6	1.2	0.5	1.6	0.6
310	2.9	0.9	2.4	0.5	3.1	0.7	1.8	0.7	2.3	0.8
311	4.3	0.7	3.8	0.7	4.6	0.8	3.7	0.5	4.4	0.6
312	4.2	0.7	4.0	0.5	4.8	0.6	3.8	0.5	4.6	0.6
313	4.6	0.6	6.0	0.4	7.1	0.5	5.8	0.6	6.9	0.7
314	3.5	0.6	4.3	0.5	5.3	0.6	4.3	0.5	5.1	0.6
315	3.2	0.5	4.2	0.4	5.1	0.4	4.2	0.5	5.0	0.6
316	2.1	1.0	4.0	0.4	4.8	0.5	4.1	0.6	5.0	0.7
317	3.3	0.4	4.0	0.3	4.8	0.4	3.6	0.4	4.2	0.4
318	3.6	0.3	4.7	0.3	5.5	0.4	4.6	0.5	5.5	0.6
401	3.2	0.4	4.1	0.7	4.8	0.8	4.3	0.5	5.0	0.5
402	2.9	0.5	3.5	0.5	4.4	0.6	3.5	0.3	4.3	0.3
403	3.3	0.5	4.2	0.7	5.0	0.7	4.3	0.7	5.0	0.7
404	3.5	0.4	4.1	0.7	4.9	0.7	4.2	0.6	5.0	0.7
405	3.2	0.4	4.1	0.7	4.8	0.7	4.8	0.7	5.8	0.8
406	2.8	0.5	3.5	0.6	4.2	0.6	3.6	0.4	4.6	0.6
407	3.0	0.6	4.2	0.5	5.0	0.6	4.0	0.2	4.7	0.4
408	3.0	1.0	4.1	0.4	4.8	0.5	4.5	0.5	5.2	0.6
409	3.4	0.5	4.3	0.6	5.1	0.7	5.3	0.6	6.1	0.7
410	2.4	0.3	3.3	0.6	4.0	0.7	3.5	0.5	4.3	0.6
411	3.5	0.6	4.8	0.6	5.6	0.7	5.8	0.8	6.8	0.9
412	3.8	0.5	6.6	1.1	7.8	1.2	6.7	1.0	7.8	1.2
413	3.5	0.3	4.6	0.6	5.5	0.7	5.1	0.5	6.0	0.6
414	3.4	0.3	4.5	0.7	5.4	0.7	5.6	0.6	6.8	0.8
415	2.8	0.6	4.3	0.4	5.0	0.5	4.3	0.5	5.0	0.6
501	2.8	0.3	3.4	0.8	4.1	0.9	3.9	0.6	4.7	0.7
502	3.1	0.2	3.6	1.0	4.3	1.3	2.6	1.5	3.1	1.8
503	3.7	0.4	4.9	0.7	5.9	0.8	5.4	0.6	6.5	0.7
504	3.1	0.3	4.1	0.7	5.0	0.9	4.7	0.5	5.6	0.6
505	4.4	0.5	5.0	0.5	6.1	0.6	5.6	0.5	6.8	0.6
506	2.6	0.3	3.7	0.7	4.5	0.9	4.1	0.6	4.9	0.7
507	3.6	0.6	4.8	0.8	5.5	0.9	5.4	0.8	6.3	0.9
508	3.2	0.5	4.3	0.7	5.0	0.8	4.5	0.8	5.3	1.0
509	2.6	0.3	3.3	0.3	3.9	0.4	3.6	0.5	4.3	0.6
510	2.7	0.8	4.3	0.8	5.1	0.9	4.8	0.6	5.7	0.7
511	3.7	0.6	4.8	0.8	5.6	0.8	5.1	0.7	6.0	0.9
512	2.5	0.3	3.3	0.5	3.9	0.6	3.1	0.5	3.7	0.6
513	3.3	0.5	4.6	0.7	5.6	0.8	4.7	0.9	5.6	1.1
514	3.2	0.5	4.0	0.7	4.8	0.8	4.2	0.6	5.0	0.7
601	3.0	0.5	3.9	0.6	4.7	0.7	4.4	0.5	5.2	0.6
602	3.0	0.4	4.0	0.7	4.9	0.8	4.6	0.6	5.5	0.7
603	2.9	0.5	3.9	0.5	4.7	0.6	4.4	0.6	5.2	0.7
604	3.2	1.3	5.4	0.7	6.3	0.8	5.6	0.7	6.5	0.8
701	3.0	0.5	3.8	1.1	4.4	1.2	3.9	0.4	4.7	0.5
702	2.9	0.5	3.6	0.7	4.3	0.8	3.7	0.6	4.4	0.7
703	3.0	0.4	3.7	0.8	4.5	0.8	3.8	0.4	4.6	0.4
704	3.1	0.5	4.1	0.9	4.8	1.0	4.1	0.5	4.9	0.6
705	3.2	0.5	4.2	0.6	4.9	0.7	4.1	0.7	4.8	0.7
706	2.8	0.4	3.3	0.6	4.0	0.6	3.3	0.5	4.0	0.6
707	2.9	0.5	4.0	0.8	4.8	1.0	4.0	0.8	4.7	1.0
708	3.0	0.4	3.8	0.8	4.5	0.9	3.6	0.9	4.3	1.1
709	2.5	0.8	4.0	0.8	4.7	0.9	4.1	0.7	4.7	0.8
710	2.9	0.5	3.9	0.7	4.6	0.8	3.7	1.0	4.3	1.2
711	2.5	0.3	3.1	0.7	3.7	0.9	3.3	0.4	4.0	0.5
712	2.6	0.4	4.0	0.7	4.6	0.8	4.1	0.6	4.8	0.6
713	2.1	0.4	3.1	0.4	3.8	0.6	2.9	0.3	3.5	0.4
714	2.9	0.5	3.8	0.7	4.6	0.9	4.1	0.5	5.0	0.7
801	3.2	0.6	4.4	0.7	5.3	0.9	4.7	0.7	5.6	0.9
802	3.5	0.7	4.5	0.7	5.4	0.8	4.4	0.5	5.2	0.6
803	3.4	0.8	4.7	0.3	5.7	0.3	4.9	0.4	5.7	0.5
804	2.8	0.7	3.7	0.6	4.5	0.6	4.0	0.6	4.8	0.7
805	4.4	0.5	5.0	0.5	6.1	0.5	5.0	0.4	5.9	0.5
806	4.5	0.4	5.6	0.4	6.4	0.5	5.1	0.5	6.0	0.6

Appendix A.4 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	Mg/ha									
807	4.8	0.4	6.1	0.4	7.3	0.5	5.6	0.7	6.6	0.9
808	4.5	0.6	4.6	0.5	5.5	0.5	4.3	0.8	5.0	0.9
809	3.9	0.5	4.6	0.6	5.5	0.7	4.3	0.5	5.0	0.7
901	3.1	0.7	1.8	0.9	2.5	1.3	2.3	0.4	3.3	0.6
902	3.0	0.6	2.3	1.2	3.1	1.5	3.1	0.7	4.0	0.9
903	3.1	0.5	3.9	0.9	4.7	1.0	4.0	0.6	4.6	0.7
1001	3.6	1.5	4.2	0.5	4.8	0.5	4.5	0.4	5.1	0.4
1002	1.3	1.0	2.1	0.7	2.9	1.0	2.1	0.8	3.0	1.1
1003	2.7	1.0	1.7	0.7	2.5	1.0	1.5	0.6	2.2	0.7
1004	2.6	0.8	2.4	0.8	3.2	1.0	2.2	0.4	3.0	0.6
1005	2.3	0.7	1.5	1.0	2.1	1.3	1.5	0.4	2.1	0.6
1006	2.2	0.8	1.9	1.0	2.7	1.2	1.8	0.5	2.6	0.7
1007	2.8	1.9	4.3	2.4	5.0	2.8	5.4	0.6	6.3	0.7
1008	1.6	0.8	0.6	0.2	0.8	0.3	0.6	0.2	0.8	0.2
1009	2.9	0.8	2.0	0.8	2.7	1.0	1.9	0.6	2.7	0.8
1010	2.3	0.7	1.6	0.9	2.3	1.1	1.3	0.4	1.8	0.6
1011	2.9	0.6	2.2	1.3	3.0	1.6	2.1	0.6	3.0	0.6
1012	3.2	0.9	3.6	1.3	4.8	1.2	3.3	1.0	4.5	1.2
1013	3.1	0.5	2.5	0.9	3.5	1.0	2.1	0.7	3.1	0.8
1014	3.0	0.5	2.8	1.1	3.9	1.3	2.7	0.6	3.8	0.7
1015	2.8	0.7	2.8	0.9	3.9	1.0	2.5	0.8	3.6	1.0
1016	3.0	0.5	2.8	1.1	4.0	1.3	2.7	0.7	3.6	0.9
1017	3.0	0.4	3.9	0.6	4.6	0.7	3.8	0.8	4.4	0.9
1018	2.2	0.8	1.7	0.5	2.5	0.7	1.8	0.5	2.6	0.7
1019	2.3	0.8	1.4	0.5	2.1	0.7	1.3	0.4	1.9	0.7
1020	3.1	0.4	3.7	1.0	4.7	1.0	4.1	1.1	4.9	1.3
1021	3.0	0.5	3.9	0.6	4.9	0.6	3.8	0.8	4.7	0.9
1022	2.9	0.5	3.2	0.8	4.2	0.8	3.7	0.8	4.6	0.8
1023	2.8	0.5	3.8	0.9	4.5	1.0	3.6	0.9	4.2	1.1
1024	2.7	0.7	3.7	0.7	4.3	0.8	4.1	0.7	4.8	0.8
1025	2.9	0.4	2.4	1.0	3.3	1.1	2.5	0.8	3.6	1.0
1026	3.3	0.6	2.6	1.0	3.8	1.0	3.6	1.1	5.0	1.5
1027	2.9	0.5	3.0	1.2	3.9	1.4	4.3	1.1	5.1	1.4
1028	2.9	0.4	3.8	0.9	4.5	1.0	4.2	0.7	4.9	0.9
1029	3.4	0.5	4.5	0.9	5.2	1.0	4.9	0.8	5.7	0.9
1030	2.8	0.7	3.9	0.8	4.6	1.0	4.4	0.8	5.0	0.9
1101	3.2	0.6	5.0	0.6	5.9	0.8	5.4	0.7	6.4	0.8
1102	1.2	0.7	0.9	0.4	1.3	0.6	1.2	0.3	1.8	0.5
1103	3.6	0.6	2.5	1.0	3.7	1.3	3.6	1.0	5.3	1.1
1104	2.1	0.9	1.4	0.8	2.1	1.1	1.7	0.5	2.6	0.8
1105	4.9	0.7	4.3	0.8	6.0	0.8	5.3	1.4	6.7	1.3
1106	4.3	0.8	4.3	1.1	5.9	1.4	5.6	0.9	6.8	0.8
1107	4.5	0.7	4.8	0.9	5.6	1.1	5.9	0.9	7.0	1.1
1108	2.5	1.1	1.3	0.5	2.0	0.7	1.8	0.9	2.7	1.4
1109	2.2	1.0	1.8	0.8	3.0	1.4	2.4	0.8	3.6	1.1
1110	3.6	0.9	2.8	1.0	4.2	1.2	3.9	1.3	5.4	1.5
1111	2.6	0.5	3.3	0.4	4.0	0.5	3.5	0.5	4.2	0.5
1112	2.9	1.1	2.6	1.0	3.8	1.5	3.1	1.1	4.4	1.3

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 – 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	Mg/ha									
1113	4.5	1.0	4.7	1.5	6.3	1.5	4.7	1.6	5.9	1.6
1114	4.2	1.3	6.2	1.1	6.7	1.5	5.0	1.3	5.6	1.6
1201	4.5	1.3	5.8	1.3	6.2	1.4	4.1	1.5	4.5	1.7
1202	5.3	0.9	5.6	1.2	6.4	1.4	4.1	0.8	4.8	1.0
1203	5.6	1.3	5.3	1.5	6.1	1.5	3.3	1.0	3.7	1.0
1204	5.0	1.0	4.5	2.1	5.2	2.4	2.8	2.2	3.2	2.5
1205	2.8	1.1	2.7	1.1	3.8	1.5	2.7	1.0	3.9	1.4
1206	3.9	1.7	4.5	1.0	6.0	1.1	3.9	1.0	4.9	1.2
1207	4.5	1.4	4.4	1.2	5.3	1.7	3.1	1.0	3.6	1.3
1208	2.5	1.5	2.3	0.9	3.2	1.3	2.1	0.8	3.0	1.0
1209	4.9	1.2	4.3	1.5	5.5	1.7	3.7	1.1	4.4	0.9
1210	3.7	1.1	3.8	1.1	4.6	1.3	2.5	0.8	2.9	0.9
1211	3.8	1.6	2.9	1.1	4.1	1.4	2.2	1.4	3.1	1.4
1301	1.1	0.7	0.7	0.3	1.1	0.5	0.9	0.2	1.3	0.3
1302	0.9	0.7	1.0	0.4	1.4	0.5	1.3	0.7	1.8	1.0
1303	1.5	1.1	1.3	0.6	1.8	0.8	1.7	1.1	2.3	1.4
1304	2.2	1.1	1.9	0.8	2.6	1.1	2.2	1.1	2.8	1.3
1305	1.1	1.0	3.9	1.9	5.4	2.4	4.0	1.0	5.9	1.6
1306	1.2	1.1	1.1	0.5	1.6	0.8	1.3	0.6	1.8	0.9
1307	1.5	1.3	1.2	0.7	1.7	0.9	1.2	0.9	1.6	1.1
1308	3.2	0.8	2.7	0.8	3.6	1.0	1.7	0.8	2.2	0.9
1309	2.4	0.7	1.9	0.5	2.6	0.6	1.0	0.5	1.3	0.6
1401	2.5	1.0	3.4	1.8	4.3	2.2	4.4	0.4	5.2	0.4
1402	1.0	0.6	1.6	1.0	2.4	1.5	3.0	0.8	4.1	0.8
1403	2.4	1.1	1.3	0.3	1.9	0.5	2.5	0.8	3.5	1.3
1404	0.6	0.3	0.5	0.3	0.8	0.4	0.8	0.3	1.1	0.4
1405	2.2	1.1	2.7	0.9	3.9	1.1	4.0	1.4	4.9	1.5
1406	1.4	0.8	1.1	0.5	1.6	0.7	2.0	0.8	2.9	1.4
1407	0.8	0.5	1.0	0.4	1.3	0.5	1.7	0.5	2.3	0.7
1408	1.0	0.7	0.6	0.3	0.8	0.4	1.1	0.5	1.5	0.7
1501	1.0	0.6	1.5	0.5	2.2	0.8	4.0	1.7	5.4	2.1
1502	0.5	0.4	0.8	0.4	1.1	0.6	1.5	0.5	2.1	0.7
1503	1.1	0.7	0.6	0.3	0.9	0.4	1.3	0.7	1.8	1.0
1504	1.5	0.8	1.4	0.5	2.0	0.7	1.5	0.6	2.1	0.8
1505	2.2	0.8	3.3	1.5	4.4	2.1	5.2	1.9	6.1	2.1
1506	3.9	2.0	4.0	1.2	6.1	1.8	7.2	2.0	8.9	2.3
1507	0.8	0.6	1.0	0.5	1.4	0.7	2.3	1.1	3.1	1.5
1508	2.2	1.5	2.2	0.8	3.1	1.1	3.6	1.5	4.8	1.9
1601	3.1	0.9	1.3	0.4	1.8	0.6	3.1	1.4	4.1	1.3
1602	1.0	0.7	1.3	0.6	1.8	0.8	2.3	0.9	3.3	1.5
1603	1.1	0.6	1.0	0.4	1.4	0.5	2.0	0.8	2.8	1.1
1604	1.0	0.5	1.5	0.5	2.1	0.7	2.3	0.9	3.2	1.2
1605	1.1	0.6	1.1	0.4	1.5	0.5	1.6	0.6	2.1	0.8
1606	0.9	0.6	0.6	0.3	0.9	0.5	1.2	0.5	1.7	0.6
1701	3.9	0.6	4.6	1.2	5.7	1.2	4.7	0.6	5.9	0.6
1702	2.4	1.1	1.5	0.3	2.2	0.7	1.7	0.2	2.4	0.4
1703	3.2	1.4	5.3	0.5	6.5	0.6	6.0	0.5	7.1	0.7
1704	2.3	0.9	1.2	0.5	1.7	0.7	1.5	0.6	2.2	1.1

Appendix A.4 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$
	---Mg/ha---									
1705	1.5	1.0	1.6	0.5	2.3	0.9	2.5	1.0	3.6	1.5
1706	3.8	1.5	1.6	2.5	1.8	2.9	3.7	2.3	4.3	2.6
1707	3.6	1.0	2.2	0.7	3.3	1.1	2.6	0.8	3.9	1.2
1708	5.5	1.1	6.4	1.0	7.1	1.1	6.8	0.6	7.7	0.7
1709	4.9	1.2	6.9	0.4	8.2	0.4	6.5	0.4	7.6	0.5
1710	5.3	0.5	6.4	0.3	7.6	0.3	6.3	0.4	7.5	0.5
1711	5.9	0.5	6.9	0.4	8.0	0.5	6.7	0.4	7.9	0.5
1712	2.3	1.0	1.2	0.3	1.7	0.5	1.7	0.5	2.3	0.7
1801	3.3	0.4	2.6	1.6	3.3	1.9	3.9	0.8	4.5	0.7
1802	2.2	2.0	4.3	1.7	4.9	2.0	3.9	1.6	4.3	1.8
1803	3.6	0.9	3.5	0.7	4.4	0.5	3.7	0.4	4.4	0.5
1804	4.4	1.0	4.6	0.3	5.3	0.3	4.4	0.4	5.2	0.5
1805	3.3	0.8	3.7	0.8	4.0	1.1	2.3	1.1	2.5	1.3
1806	3.6	0.4	3.2	0.2	3.8	0.3	2.6	0.2	3.1	0.3
1807	3.6	1.2	4.0	0.5	4.8	0.4	3.6	0.4	4.2	0.5
1808	2.3	1.7	2.5	1.4	3.4	1.8	3.5	0.9	4.7	1.0
1809	0.7	0.8	0.5	0.3	0.8	0.4	1.3	0.7	1.8	0.9
1810	0.7	0.7	0.6	0.3	0.8	0.4	1.3	0.6	1.8	0.8

Appendix A.5: EPIC simulated mean yields and standard deviation for alfalfa under dryland management for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect.

USGS Four Digit Basin	Baseline [CO_2] = 365		Hadley (2025-2034) 365		Hadley (2025-2034) 560		Hadley (2090 - 2099) 365		Hadley (2090 - 2099) 560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	Mg/ha									
401	7.7	0.6	8.6	0.9	10.5	1.0	9.6	1.0	11.6	1.1
402	5.3	1.0	6.5	1.0	7.9	1.3	6.7	1.0	8.2	1.1
403	6.2	1.1	7.5	1.3	9.2	1.5	7.8	1.3	9.5	1.6
404	6.6	1.1	7.8	1.0	9.3	1.3	8.2	1.6	9.8	2.0
405	6.3	1.2	7.4	1.4	9.0	1.7	8.0	1.2	9.3	1.4
406	5.8	1.0	6.7	1.0	8.2	1.1	6.7	1.6	8.4	1.8
407	6.3	0.9	7.5	1.0	9.1	1.0	8.1	1.5	9.9	1.8
408	6.6	1.2	7.1	1.4	8.7	1.6	7.1	0.8	8.7	1.0
409	6.5	1.1	7.7	1.4	9.3	1.7	8.1	1.5	9.4	1.5
410	7.4	0.8	8.9	0.9	10.7	1.1	9.0	1.2	10.7	1.4
411	8.0	0.7	9.3	1.0	11.3	1.3	9.5	0.8	11.5	1.0
504	7.3	0.8	8.4	1.0	10.1	1.1	8.8	0.8	10.5	1.0
506	7.8	0.8	9.1	1.0	10.9	1.1	9.5	0.6	11.1	0.8
508	9.2	0.9	10.9	1.0	13.0	1.2	11.1	1.4	13.1	1.6
509	9.3	0.7	10.0	1.0	11.8	1.1	10.2	0.6	11.9	0.7
512	7.2	0.7	8.1	1.0	9.6	1.1	9.2	1.7	10.6	1.7
701	8.4	0.8	9.1	1.3	11.3	1.2	9.8	1.2	12.1	1.4
702	8.6	1.5	7.5	2.2	9.8	2.5	8.6	2.0	11.1	2.4
703	6.5	1.1	7.1	1.4	8.7	1.6	7.2	1.3	8.9	1.6
704	9.3	1.3	10.3	1.6	12.9	1.3	11.2	1.6	13.6	1.8
705	6.2	1.0	8.5	1.7	10.1	2.0	8.4	1.0	9.9	1.2
706	7.3	1.2	7.7	1.3	9.5	1.2	8.1	1.5	9.7	1.8
707	6.6	1.1	8.1	1.8	9.9	2.2	8.1	1.4	9.8	1.7
708	7.5	1.4	7.5	1.6	9.2	1.5	8.8	1.9	10.5	2.2
709	6.3	1.2	7.1	0.9	8.7	1.0	7.8	1.2	9.3	1.5
710	7.2	1.1	7.4	1.5	9.1	1.6	8.6	1.3	10.4	1.9
712	6.3	0.9	8.3	1.3	9.8	1.5	9.0	1.3	10.7	1.6
713	5.2	0.5	7.9	1.9	9.4	2.3	7.6	1.2	9.4	1.8
714	9.1	0.8	9.9	1.8	12.0	1.9	10.2	1.2	12.3	1.3
901	5.3	1.3	3.3	0.9	4.4	1.2	3.7	1.2	5.0	1.5
902	6.6	1.2	3.9	1.4	5.2	1.7	4.7	1.5	6.3	1.9
903	7.4	1.0	7.5	1.5	9.6	1.4	9.1	1.3	11.2	1.4
1001	5.8	1.9	6.9	1.0	8.3	1.2	7.8	0.6	9.5	0.7
1002	3.0	0.8	4.0	0.9	5.2	1.2	3.5	1.0	4.6	1.2
1003	4.2	1.3	3.3	0.9	4.4	1.2	2.7	0.5	3.7	0.6
1004	4.1	1.1	4.2	0.9	5.4	1.1	3.9	0.7	5.1	0.9
1005	3.5	1.2	3.0	1.1	4.0	1.4	2.7	0.6	3.6	0.7
1006	3.5	1.3	3.4	1.2	4.5	1.5	3.1	1.1	4.1	1.4
1007	5.5	1.0	8.1	0.7	10.1	0.8	8.2	0.6	10.1	0.7
1008	2.2	0.7	1.0	0.2	1.3	0.3	1.2	0.2	1.6	0.3
1009	3.9	0.9	3.1	0.9	4.0	1.1	3.1	0.6	4.1	0.8
1010	3.6	1.2	3.1	0.9	4.0	1.1	2.6	0.5	3.5	0.7
1011	4.5	1.3	3.5	1.2	4.6	1.5	3.5	1.4	4.7	1.7
1012	4.4	1.2	4.5	1.0	5.8	1.1	4.2	0.8	5.5	0.9
1013	5.1	1.3	3.8	1.1	5.0	1.3	3.7	0.8	4.9	1.0

USGS Four Digit Basin	Baseline [CO_2] = 365		Hadley (2025-2034) 365		Hadley (2025-2034) 560		Hadley (2090 - 2099) 365		Hadley (2090 - 2099) 560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	Mg/ha									
1014	3.9	1.0	4.0	0.9	5.3	0.9	3.8	0.6	4.9	0.7
1015	4.6	1.2	4.3	0.9	5.7	1.1	4.0	0.9	5.3	1.2
1016	4.7	1.2	3.7	1.0	4.8	1.2	3.9	1.0	5.2	1.1
1017	5.7	0.7	5.6	1.0	7.2	1.0	6.3	1.1	7.9	1.3
1018	3.0	0.9	2.6	0.4	3.4	0.6	2.4	0.4	3.0	0.5
1019	3.5	1.1	2.7	0.5	3.7	0.6	2.3	0.6	3.1	0.7
1020	6.4	1.2	6.1	1.9	8.0	2.4	7.3	1.6	9.4	1.8
1021	6.5	1.2	5.9	1.2	7.7	1.6	6.5	1.0	8.6	1.1
1022	6.2	1.5	5.4	1.8	7.0	2.2	6.6	1.4	8.7	1.6
1023	8.5	1.2	8.0	1.8	10.0	1.7	9.1	1.0	10.7	1.1
1024	7.5	0.9	8.3	1.7	10.2	1.6	9.7	1.6	11.6	1.9
1025	4.5	0.8	4.0	1.0	5.3	1.2	4.5	1.1	6.0	1.4
1026	5.5	1.2	4.4	1.2	5.8	1.6	4.9	1.3	6.7	1.5
1027	7.5	0.9	6.2	2.8	8.2	3.4	7.3	2.0	9.4	2.3
1102	2.2	0.8	2.0	0.5	2.8	0.6	2.0	0.5	2.7	0.6
1103	5.9	1.4	4.5	1.2	6.1	1.5	5.5	0.7	7.4	1.0
1104	3.3	0.9	2.8	1.1	3.9	1.4	2.9	0.8	4.0	1.0
1107	9.8	2.0	8.5	1.7	11.1	2.0	9.9	2.0	12.7	2.9
1108	3.0	1.1	1.7	0.8	2.3	1.1	1.7	0.7	2.4	0.8
1301	3.0	0.9	1.9	0.6	2.6	0.8	2.2	0.4	3.1	0.6
1302	1.5	0.7	1.3	0.5	1.7	0.7	1.8	0.7	2.6	0.8
1303	1.8	1.1	2.0	1.0	2.8	1.4	2.3	0.9	3.2	1.2
1305	1.5	1.2	4.9	1.6	6.4	2.0	5.7	2.4	7.4	2.8
1306	1.7	1.1	1.4	0.7	1.9	0.9	1.3	0.8	2.0	1.2
1401	4.9	0.9	6.5	0.9	8.2	0.9	6.4	0.5	8.1	0.6
1402	2.7	0.8	4.8	1.2	6.3	1.4	5.5	0.7	7.2	0.9
1403	4.7	1.1	2.6	0.5	3.5	0.6	3.7	0.9	5.0	1.1
1404	1.3	0.5	1.1	0.4	1.6	0.6	1.5	0.5	2.2	0.7
1405	4.0	1.2	5.1	1.0	6.7	1.2	6.1	1.3	7.9	1.5
1406	2.7	1.3	2.8	0.9	3.8	1.1	3.8	1.0	4.9	1.2
1407	2.0	1.0	1.5	0.5	2.0	0.6	2.4	0.6	3.1	0.9
1408	1.6	0.8	0.9	0.4	1.2	0.6	1.5	0.6	2.1	0.8
1501	1.0	1.0	1.5	1.2	2.4	1.6	3.9	2.2	5.3	2.6
1502	1.1	0.8	0.6	0.4	0.8	0.4	1.6	1.2	2.2	1.5
1503	0.7	0.6	0.5	0.4	0.6	0.6	0.8	0.6	1.1	0.9
1504	1.9	0.8	2.2	0.8	2.9	1.0	2.8	1.2	3.7	1.5
1505	3.6	1.5	3.4	2.0	4.6	2.2	4.4	2.1	5.5	2.8
1506	4.1	2.2	6.1	1.9	8.3	2.4	7.0	3.4	9.1	4.0
1507	0.6	0.6	0.7	0.8	1.0	1.1	2.1	1.6	2.9	2.1
1508	2.5	1.8	2.2	1.7	3.1	2.2	3.2	1.5	4.0	1.9
1601	5.3	1.4	3.0	0.8	4.0	1.1	4.8	1.4	6.3	1.8
1602	1.9	0.7	2.4	0.7	3.1	0.9	3.5	1.2	4.5	1.5
1603	2.5	0.8	2.0	0.6	2.7	0.8	3.4	1.1	4.5	1.5
1604	1.9	0.9	3.0	0.8	4.0	1.0	4.2	1.1	5.5	1.4
1605	2.3	0.6	2.1	0.6	2.8	0.8	2.7	1.0	3.6	1.3

Appendix A.5 (cont.)

USGS Four Digit Basin	Baseline [CO_2] = 365		Hadley (2025-2034) 365		Hadley (2025-2034) 560		Hadley (2090 - 2099) 365		Hadley (2090 - 2099) 560	
	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$
	---Mg/ha---									
1606	2.2	0.9	1.4	0.6	1.9	0.8	2.3	0.9	3.1	1.2
1701	7.4	0.8	6.8	1.0	8.8	1.1	6.4	1.0	8.1	1.2
1702	4.1	1.4	3.5	0.9	4.8	1.2	3.4	0.7	4.6	1.0
1703	5.1	0.4	7.3	0.8	9.5	0.9	8.1	1.5	10.6	1.9
1704	3.8	0.9	2.9	0.8	3.9	1.1	3.2	1.1	4.3	1.4
1705	2.5	1.1	3.3	0.8	4.4	1.0	4.1	1.6	5.4	2.1
1706	8.8	0.8	9.2	0.8	11.1	1.0	10.4	1.0	12.6	1.2
1707	4.9	1.7	3.9	1.0	5.1	1.2	3.8	1.2	5.2	1.5
1708	10.8	2.0	10.9	1.1	13.1	1.4	12.1	2.6	14.5	2.9
1709	8.4	1.5	9.3	1.4	11.4	1.5	9.9	1.9	12.0	1.8
1710	8.3	1.5	8.0	1.7	10.1	1.9	9.0	1.0	11.6	1.4
1711	10.3	1.8	12.3	1.6	14.6	2.0	13.2	2.9	15.7	3.5
1712	3.0	1.1	1.9	0.8	2.7	1.1	2.3	0.9	3.0	1.3
1801	1.5	0.6	1.6	0.4	2.3	1.0	2.3	0.9	3.5	1.9
1802	3.5	0.7	3.7	1.2	4.8	1.4	3.9	1.5	5.8	2.0
1803	1.8	1.8	1.1	0.5	2.6	2.4	2.1	2.3	3.4	3.1
1804	2.8	0.6	2.5	0.7	3.8	2.1	3.3	2.1	5.5	3.2
1805	1.9	0.8	1.9	0.6	2.4	0.7	1.6	0.3	2.2	0.4
1806	2.2	1.0	1.9	1.6	2.6	2.2	1.9	0.4	2.8	1.8
1807	6.4	3.1	8.9	2.9	11.1	3.6	11.2	3.2	14.0	3.8
1808	1.4	0.5	1.4	0.5	1.9	0.7	1.6	0.6	2.2	0.7
1809	0.4	0.4	0.2	0.1	0.2	0.1	0.3	0.1	0.4	0.2
1810	1.5	1.1	1.1	1.1	1.7	1.2	2.7	1.4	3.5	1.8

Appendix B.1: EPIC simulated mean yields and standard deviations for corn under irrigation for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect.

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	----Mg/ha----									
101	3.9	0.5	5.4	0.4	5.8	0.4	5.3	0.4	5.7	0.4
102	3.5	0.3	4.4	0.5	4.8	0.6	4.1	0.4	4.5	0.4
103	4.2	0.4	4.9	0.6	5.2	0.6	5.1	0.4	5.5	0.4
104	4.2	0.3	5.4	0.5	5.8	0.5	5.2	0.4	5.6	0.4
105	3.1	0.5	3.6	0.6	4.0	0.7	3.4	0.5	3.8	0.5
106	4.1	0.4	5.5	0.6	5.9	0.6	5.5	0.2	5.9	0.3
107	4.1	0.4	5.4	0.5	5.8	0.6	5.3	0.3	5.6	0.3
108	4.9	0.4	6.1	0.7	6.5	0.8	6.0	0.4	6.4	0.5
109	3.8	0.4	4.3	0.5	4.8	0.5	4.5	0.5	4.9	0.6
110	4.2	0.3	5.0	0.7	5.4	0.7	5.0	0.5	5.6	0.5
111	4.8	0.4	5.4	0.8	5.9	0.8	5.9	0.4	6.3	0.4
201	4.1	0.6	5.8	0.6	6.3	0.6	5.8	0.4	6.2	0.4
202	3.6	0.3	4.9	0.8	5.3	0.8	4.9	0.4	5.3	0.4
203	3.9	0.3	4.7	0.8	5.2	0.8	4.6	0.5	5.1	0.5
204	5.9	0.4	6.8	1.0	7.3	1.1	6.8	0.5	7.2	0.6
205	5.5	0.8	6.4	0.9	6.9	1.0	6.6	0.6	7.0	0.6
206	3.9	0.8	3.6	1.0	4.3	1.1	3.4	0.7	4.0	0.8
207	3.7	0.7	4.1	0.8	4.8	0.9	4.6	1.0	5.3	1.1
208	7.6	1.1	8.2	0.7	8.8	0.8	7.7	0.8	8.3	0.8
301	5.4	1.2	5.6	0.8	6.3	0.9	5.4	0.8	6.0	0.8
302	4.3	1.0	4.1	1.0	4.8	1.1	3.6	0.9	4.3	0.9
303	4.8	0.6	4.6	1.2	5.3	1.3	4.3	0.6	5.0	0.6
304	4.5	0.4	4.0	1.0	4.6	1.1	4.3	0.6	4.9	0.7
305	6.0	0.5	5.8	0.8	6.5	0.9	5.9	0.9	6.7	0.9
306	4.9	1.6	4.9	1.0	5.6	1.1	5.1	0.8	5.8	0.9
307	5.1	0.6	4.6	0.9	5.2	1.0	4.6	0.9	5.2	1.1
308	6.0	0.3	6.0	0.8	6.7	0.8	5.0	0.7	5.7	0.7
309	5.2	0.9	3.6	1.3	4.3	1.3	2.2	1.0	2.8	1.2
310	7.6	1.0	7.7	0.4	8.4	0.5	6.7	0.6	7.3	0.6
311	5.1	0.4	4.5	0.8	5.1	1.0	4.1	1.0	4.6	1.1
312	5.1	0.7	4.4	1.1	5.0	1.2	3.7	0.9	4.2	1.1
313	4.3	0.5	3.2	1.1	3.9	1.2	3.1	1.3	3.7	1.4
314	5.3	1.1	5.9	0.9	6.7	1.0	5.7	0.8	6.4	0.8
315	8.4	0.5	9.7	1.1	10.4	1.2	9.3	1.1	10.0	1.2
316	4.3	2.4	6.2	1.0	6.8	1.0	6.0	0.7	6.7	0.9
317	7.9	0.5	8.3	1.1	8.9	1.1	7.7	1.1	8.3	1.1
318	7.2	0.4	8.1	1.0	8.7	1.1	7.6	1.0	8.2	1.1
401	3.2	1.2	4.2	2.0	4.6	2.1	5.6	1.1	6.0	1.2
402	2.5	1.1	4.2	1.3	4.5	1.5	5.7	0.5	6.2	0.5
403	4.0	0.9	5.2	1.2	5.5	1.3	6.5	0.5	7.0	0.5
404	5.6	0.3	5.9	0.8	6.3	0.9	6.2	0.4	6.6	0.4
405	5.4	0.3	6.4	0.7	6.9	0.8	6.5	0.6	6.9	0.7
406	3.9	2.1	6.0	0.4	6.5	0.3	6.2	0.3	6.8	0.3
407	4.9	0.9	6.2	0.5	6.7	0.5	6.7	0.3	7.3	0.3
408	4.9	1.7	6.3	0.5	6.8	0.5	6.4	0.3	6.9	0.4
409	5.7	0.3	6.5	0.7	7.0	0.7	6.4	0.5	6.9	0.5
410	5.8	0.4	6.4	1.0	6.9	1.0	6.4	0.6	6.9	0.7
411	6.3	0.4	6.7	0.9	7.2	1.0	6.7	0.7	7.2	0.7
412	5.1	1.5	0.7	0.8	0.7	0.9	1.4	1.4	1.5	1.5
413	5.3	0.3	5.8	0.7	6.1	0.7	5.8	0.4	6.3	0.4
414	4.7	0.3	5.4	0.8	5.8	0.8	5.5	0.4	5.9	0.4
415	4.1	0.7	5.4	0.7	5.9	0.7	5.4	0.4	5.7	0.6
501	2.5	0.9	5.6	1.5	6.0	1.6	6.3	0.5	6.8	0.6
502	5.9	0.6	7.1	0.7	7.6	0.8	7.4	0.6	7.9	0.6
503	6.3	0.4	7.1	0.8	7.7	0.8	7.1	0.7	7.6	0.7
504	6.1	0.4	6.8	0.8	7.3	0.9	6.8	0.6	7.3	0.6
505	6.9	0.5	7.0	0.5	7.5	0.5	7.1	0.5	7.6	0.5
506	6.0	0.4	6.8	0.7	7.3	0.7	6.9	0.8	7.4	0.8
507	9.0	0.5	8.8	0.8	9.4	0.9	8.7	0.9	9.3	1.0
508	6.8	0.4	7.4	0.7	8.0	0.8	7.4	0.8	7.9	0.8
509	6.1	0.5	6.5	1.0	7.0	1.0	6.6	0.8	7.1	0.8
510	6.8	3.2	7.7	0.9	8.2	1.0	7.8	1.0	8.3	1.1
511	7.0	0.4	6.8	0.6	7.4	0.7	6.7	1.0	7.3	1.1
512	6.7	0.4	6.6	1.2	7.1	1.2	6.6	0.9	7.1	1.0
513	7.7	0.5	7.6	0.8	8.2	0.8	7.3	1.0	7.9	1.0
514	7.6	0.4	7.0	0.9	7.6	0.9	7.1	1.1	7.6	1.1
601	6.8	1.5	7.9	0.7	8.5	0.8	7.7	0.8	8.3	0.8
602	6.1	0.4	6.8	1.0	7.6	1.1	7.1	1.1	7.6	1.2
603	8.1	0.5	9.2	1.2	9.8	1.3	9.0	1.2	9.7	1.3
604	6.4	2.1	7.6	1.0	8.1	1.1	7.7	1.2	8.2	1.2
701	5.5	0.7	6.0	1.2	6.5	1.3	7.0	0.3	7.4	0.4
702	5.9	0.4	6.7	0.8	7.2	0.8	6.6	0.7	7.1	0.7
703	5.4	0.4	5.5	1.1	5.9	1.2	6.4	0.5	6.8	0.5
704	5.8	0.3	6.6	0.9	7.1	1.0	7.0	0.5	7.5	0.5
705	3.9	1.1	6.1	1.0	6.5	1.1	6.8	0.2	7.3	0.2
706	5.9	0.3	6.5	0.8	7.0	0.8	6.9	0.6	7.3	0.6
707	5.3	0.5	6.0	1.2	6.4	1.3	6.6	0.4	7.1	0.4
708	5.8	0.4	6.5	0.8	7.0	0.8	6.6	0.6	7.1	0.6
709	4.3	1.9	6.1	0.8	6.6	0.8	6.4	0.6	6.8	0.6
710	6.0	0.4	6.7	0.9	7.2	1.0	6.8	0.8	7.3	0.8
711	6.0	0.4	6.5	1.0	7.0	1.1	6.2	1.2	6.7	1.3
712	5.2	0.4	6.2	1.0	6.7	1.1	6.3	0.9	6.8	0.9
713	6.1	0.4	6.8	1.0	7.3	1.1	6.8	1.1	7.3	1.2
714	5.5	0.3	5.7	1.0	6.2	1.0	5.7	0.9	6.1	1.0
801	6.9	0.4	6.6	1.3	7.2	1.4	6.5	1.1	7.0	1.2
802	5.7	1.6	5.8	1.1	6.1	1.0	4.1	1.2	4.1	1.2
803	3.5	1.8	3.6	1.1	3.5	1.1	2.2	1.4	2.0	1.4
804	4.5	2.2	6.2	1.3	6.5	1.4	5.2	1.4	5.2	1.4
805	4.2	2.2	6.0	1.2	6.2	1.3	4.8	1.6	5.0	1.8
806	7.6	0.5	7.8	1.1	8.4	1.2	7.4	0.9	8.0	1.0

Appendix B.1 (cont.)

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$
	---Mg/ha---									
807	5.6	0.3	7.3	0.8	7.9	0.8	6.6	0.9	7.1	0.9
808	7.2	1.9	7.6	0.9	8.2	0.9	6.5	1.2	7.0	1.3
809	6.2	0.4	7.6	0.8	8.2	0.8	6.7	1.0	7.2	1.1
901	5.3	0.8	6.0	0.4	6.5	0.5	6.1	0.3	6.6	0.3
902	5.3	0.4	6.0	0.7	6.5	0.7	6.0	0.3	6.4	0.3
903	3.1	1.5	5.0	1.7	5.3	1.9	6.3	1.0	6.7	1.1
1001	1.2	1.0	0.7	1.0	0.8	1.1	3.2	1.0	3.5	1.1
1002	2.4	1.1	4.6	1.2	4.9	1.3	5.9	0.4	6.3	0.4
1003	4.2	0.7	5.8	0.4	6.3	0.4	6.0	0.5	6.4	0.5
1004	3.7	1.9	6.0	0.4	6.5	0.4	5.9	0.5	6.3	0.5
1005	4.6	0.3	5.8	0.5	6.2	0.5	5.7	0.4	6.2	0.4
1006	4.7	0.4	5.7	0.5	6.1	0.5	5.3	0.5	5.7	0.5
1007	2.4	1.0	3.8	1.2	4.1	1.3	5.5	0.5	5.9	0.5
1008	5.1	0.3	6.4	0.6	6.8	0.6	6.1	0.4	6.6	0.4
1009	5.3	0.4	6.3	0.6	6.7	0.6	5.9	0.4	6.4	0.4
1010	4.6	0.4	5.5	0.4	5.9	0.5	5.3	0.4	5.7	0.4
1011	5.3	0.6	6.3	0.6	6.8	0.6	5.9	0.3	6.4	0.3
1012	4.8	1.0	6.3	1.4	6.7	1.5	6.5	2.3	7.0	2.5
1013	5.4	0.5	6.3	0.7	6.8	0.7	6.0	0.4	6.4	0.4
1014	5.6	0.4	6.6	0.8	7.1	0.8	6.3	0.6	6.8	0.6
1015	4.8	2.6	7.4	0.9	8.0	0.9	6.9	0.6	7.4	0.6
1016	5.9	0.6	6.8	0.9	7.3	0.9	6.7	0.4	7.2	0.5
1017	5.2	0.7	5.9	0.7	6.3	0.9	5.6	0.6	6.1	0.7
1018	5.3	0.3	6.7	0.4	7.2	0.5	6.2	0.3	6.7	0.3
1019	4.6	0.9	6.6	0.5	7.1	0.5	6.3	0.4	6.8	0.4
1020	6.0	0.4	6.6	0.8	7.1	0.8	6.3	0.8	6.8	0.9
1021	6.2	0.4	7.1	0.8	7.6	0.8	6.8	0.8	7.3	0.9
1022	5.7	0.5	6.7	0.8	7.2	0.9	6.6	0.9	7.0	0.9
1023	6.6	0.6	6.8	1.1	7.3	1.2	7.0	0.9	7.6	0.9
1024	6.0	1.5	6.9	1.1	7.4	1.2	6.8	1.2	7.3	1.3
1025	5.7	0.4	6.9	0.8	7.5	0.8	6.4	0.9	6.9	1.0
1026	6.1	1.3	6.7	1.0	7.2	1.1	6.1	1.0	6.6	1.1
1027	5.8	0.5	6.0	0.9	6.6	1.0	5.8	1.1	6.2	1.1
1028	5.8	0.8	6.7	0.8	7.3	1.0	6.3	1.2	6.8	1.3
1029	7.0	0.5	7.0	1.2	7.5	1.3	6.9	1.3	7.4	1.3
1030	7.2	0.4	7.3	1.3	7.8	1.3	7.0	1.3	7.5	1.3
1101	6.6	1.4	6.9	1.0	7.4	1.1	7.0	1.3	7.5	1.4
1102	4.5	0.9	6.4	0.6	6.9	0.6	6.0	0.6	6.5	0.6
1103	6.1	0.4	6.1	1.0	6.6	1.0	5.8	1.0	6.2	1.2
1104	5.6	1.8	6.8	1.0	7.4	1.0	6.3	0.9	6.9	0.9
1105	6.8	0.6	6.5	1.6	7.0	1.7	6.3	1.2	6.8	1.3
1106	6.5	0.6	6.3	1.4	6.8	1.5	6.0	1.3	6.5	1.4
1107	7.3	0.5	6.8	1.5	7.3	1.5	6.4	1.3	6.9	1.4
1108	0.4	1.1	6.7	0.5	7.2	0.5	5.8	0.6	6.3	0.6
1109	6.7	1.5	7.4	1.0	8.0	1.0	7.0	0.8	7.6	0.8
1110	6.6	0.5	6.4	1.1	7.0	1.1	5.8	1.0	6.3	1.1
1111	7.6	0.5	6.7	1.8	7.3	1.9	6.6	1.3	7.1	1.4
1112	6.5	0.9	6.9	0.8	7.3	0.8	6.1	0.9	6.3	1.0

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$	$\overline{X}$	$\bar{s}$
	---Mg/ha---									
1113	7.0	0.5	7.0	1.2	7.5	1.3	6.6	1.0	7.1	1.1
1114	6.6	1.3	7.3	1.1	7.8	1.2	6.2	1.9	6.7	2.1
1201	7.0	1.3	7.3	0.9	8.0	1.1	5.8	0.8	6.4	1.0
1202	9.3	0.6	8.9	0.9	9.5	0.9	7.8	1.3	8.4	1.4
1203	7.0	1.3	7.0	0.9	7.5	0.9	6.1	1.0	6.4	0.9
1204	9.1	0.5	9.1	1.0	9.7	1.0	7.8	1.0	8.4	1.1
1205	7.4	0.5	7.5	0.7	8.1	0.7	6.7	0.6	7.2	0.7
1206	7.4	0.7	6.9	1.1	7.4	1.3	5.6	1.1	6.0	1.2
1207	7.2	1.8	7.6	0.7	8.1	0.7	6.5	0.9	6.9	0.7
1208	7.8	0.5	7.9	0.8	8.6	0.8	7.0	0.8	7.6	0.9
1209	9.4	0.4	9.3	1.0	10.0	1.0	8.1	1.1	8.7	1.1
1210	8.0	0.8	8.9	0.9	9.4	0.9	7.2	0.9	7.7	0.8
1211	7.3	2.2	8.4	0.8	9.1	0.9	6.7	0.9	7.4	1.0
1301	2.4	0.8	5.2	1.7	5.7	1.9	6.9	0.4	7.4	0.5
1302	2.0	1.2	6.9	0.5	7.5	0.5	6.1	0.6	6.7	0.6
1303	6.0	0.3	5.8	0.5	6.3	0.5	4.6	0.4	5.2	0.5
1304	10.7	3.1	11.0	1.1	11.8	1.0	9.2	1.0	10.0	1.0
1305	5.6	0.3	6.4	1.6	6.9	1.7	7.0	0.2	7.6	0.2
1306	6.0	0.3	6.0	0.6	6.6	0.6	5.2	0.7	5.7	0.7
1307	9.2	0.5	8.9	1.1	9.8	1.2	7.5	1.2	8.3	1.2
1308	7.8	0.5	7.7	0.7	8.4	0.7	6.2	0.6	6.8	0.7
1309	8.2	0.5	7.5	0.7	8.1	0.7	5.8	0.6	6.4	0.7
1401	0.6	0.5	0.7	1.0	0.8	1.0	4.2	2.3	4.5	2.4
1402	0.8	0.6	1.1	1.1	1.2	1.2	5.2	2.0	5.5	2.2
1403	3.5	1.5	6.8	0.4	7.4	0.5	6.0	0.4	6.6	0.4
1404	2.9	1.1	4.5	2.0	5.3	2.1	3.7	2.0	4.3	2.1
1405	2.9	1.4	4.8	1.4	5.2	1.5	6.8	0.9	7.3	1.0
1406	4.8	1.5	7.1	0.7	7.6	0.7	6.4	0.3	6.9	0.3
1407	5.9	0.3	6.4	0.6	6.9	0.6	5.7	0.4	6.2	0.4
1408	5.0	1.4	6.2	0.5	6.7	0.6	5.2	0.4	5.8	0.3
1501	5.7	0.5	6.1	0.7	6.7	0.8	5.8	0.5	6.3	0.5
1502	6.6	0.5	7.0	0.5	7.7	0.5	6.1	0.4	6.7	0.4
1503	6.0	1.4	6.0	0.5	6.5	0.5	6.0	0.5	6.5	0.5
1504	5.7	0.3	5.5	0.6	6.1	0.6	4.7	0.4	5.3	0.4
1505	6.3	0.4	6.4	0.6	7.0	0.7	6.2	0.6	6.8	0.6
1506	6.4	0.6	7.1	0.7	7.8	0.8	6.5	0.4	7.1	0.4
1507	6.6	0.9	6.4	0.5	7.0	0.5	6.3	0.6	6.9	0.6
1508	5.3	2.9	7.1	0.5	7.8	0.5	7.0	0.7	7.5	0.7
1601	5.7	0.7	4.3	1.1	4.6	1.3	6.5	0.9	7.0	1.0
1602	5.2	0.4	6.0	0.6	6.5	0.6	5.4	0.4	5.8	0.4
1603	5.6	0.5	6.7	0.5	7.3	0.5	5.9	0.4	6.4	0.4
1604	6.3	0.5	6.8	0.6	7.3	0.6	6.1	0.6	6.6	0.6
1605	5.8	1.3	5.2	0.5	5.6	0.5	4.3	0.3	5.0	0.5
1606	6.3	1.3	6.7	0.9	7.2	0.9	5.9	2.1	6.5	2.3
1701	4.9	0.6	3.9	1.4	4.2	1.6	5.7	0.4	6.2	0.4
1702	5.0	1.5	6.6	0.7	7.1	0.7	6.4	0.8	6.9	0.8
1703	0.2	0.4	4.7	1.8	5.1	1.9	7.2	0.6	7.8	0.7
1704	4.4	0.7	6.4	0.7	6.9	0.8	5.9	0.4	6.4	0.4

Appendix B.1 (cont.)

USGS Four Digit Basin	Baseline [CO_2] = 365		Hadley (2025-2034) 365		Hadley (2025-2034) 560		Hadley (2090 - 2099) 365		Hadley (2090 - 2099) 560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	---Mg/ha---									
1705	5.6	0.4	6.2	0.5	6.6	0.6	5.9	0.6	6.4	0.6
1706	1.6	0.9	0.4	0.7	0.5	0.8	3.3	1.5	3.5	1.7
1707	5.6	0.4	6.9	0.5	7.4	0.5	6.8	0.7	7.4	0.7
1708	4.6	1.7	3.9	1.8	4.1	1.9	7.5	0.6	8.0	0.7
1709	6.7	1.5	7.4	0.3	7.9	0.3	7.3	0.6	7.9	0.7
1710	6.0	1.1	7.5	0.2	8.1	0.2	7.6	0.4	8.1	0.5
1711	3.7	1.4	5.4	1.6	5.8	1.8	7.8	0.5	8.4	0.6
1712	6.1	1.3	6.8	0.7	7.4	0.7	6.6	0.5	7.1	0.5
1801	8.6	0.7	1.3	1.0	1.5	1.1	6.8	1.3	7.4	1.4
1802	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.0	1.0	1.1
1803	9.4	0.7	7.5	0.6	8.2	0.7	7.3	0.9	8.0	0.9
1804	1.4	0.9	8.3	0.6	9.0	0.6	7.5	0.3	8.1	0.3
1805	8.9	1.6	9.5	0.2	10.3	0.3	10.0	0.3	10.7	0.3
1806	10.6	0.7	9.0	0.4	9.9	0.4	8.4	0.3	9.2	0.3
1807	7.9	0.3	6.8	0.5	7.4	0.5	6.8	0.4	7.3	0.4
1808	4.6	1.7	1.0	0.9	1.1	1.0	5.9	2.5	6.5	2.7
1809	5.2	1.5	3.7	0.9	4.2	0.9	2.6	0.4	3.0	0.4
1810	2.7	0.5	3.3	0.5	3.7	0.6	3.3	0.4	3.7	0.5

Appendix B.2: EPIC simulated mean yields and standard deviations for alfalfa under irrigation for baseline climate and Hadley climate at two time periods with and without the CO_2 fertilization effect

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	-------------------	-------------------	-------------------	-------------------	Mg/ha	-------------------	-------------------	-------------------	-------------------	-------------------
401	7.7	0.6	9.7	0.8	11.3	1.0	10.4	0.9	12.0	1.0
402	5.4	1.1	7.2	1.2	8.4	1.4	7.4	1.0	8.7	1.2
403	6.3	1.1	8.8	1.6	10.3	1.8	8.6	1.4	10.0	1.6
404	6.9	1.1	8.4	1.4	9.8	1.7	8.7	1.9	10.1	2.1
405	6.6	1.2	8.4	1.5	9.8	1.7	8.8	1.9	10.3	2.3
406	6.2	1.1	8.2	1.2	9.7	1.5	8.2	1.8	9.7	2.1
407	6.6	1.0	8.5	1.0	10.0	1.2	9.4	1.8	10.9	2.1
408	7.0	1.4	8.3	1.6	9.6	1.8	7.9	0.9	9.2	1.1
409	6.9	1.2	8.4	1.6	9.8	1.9	8.5	1.5	9.9	1.7
410	7.7	0.8	9.6	1.0	11.2	1.1	9.6	1.3	11.1	1.5
411	8.5	0.9	10.5	1.4	12.2	1.6	9.9	0.6	11.5	0.7
504	7.6	0.8	9.3	1.0	10.8	1.1	9.4	1.0	10.9	1.2
506	8.0	0.8	9.9	0.9	11.6	1.1	9.8	0.8	11.5	0.9
508	9.5	1.0	11.4	1.0	13.3	1.2	11.4	1.5	13.3	1.7
509	9.5	0.7	10.4	0.9	12.2	1.0	10.5	0.6	12.1	0.7
512	7.5	0.7	8.7	0.9	10.1	1.1	9.3	1.5	10.5	1.4
701	8.7	0.9	10.7	1.0	12.5	1.1	11.5	1.4	13.4	1.6
702	10.1	1.6	11.8	1.7	13.8	1.9	11.4	1.5	13.3	1.7
703	7.1	1.4	8.4	1.6	9.8	1.9	8.1	1.4	9.5	1.7
704	9.4	1.3	11.4	1.1	13.3	1.3	11.8	1.7	13.7	2.0
705	6.2	1.0	8.8	1.7	10.3	2.0	8.6	1.0	9.9	1.2
706	7.5	1.3	8.7	1.2	10.1	1.4	8.7	1.6	10.1	1.9
707	6.7	1.2	9.2	1.9	10.7	2.2	8.8	1.6	10.3	1.9
708	7.6	1.5	8.4	1.1	9.8	1.2	9.0	1.9	10.5	2.1
709	6.5	1.3	7.9	0.9	9.2	1.1	8.5	1.5	9.9	1.8
710	7.6	1.4	8.7	1.1	10.1	1.3	9.2	1.8	10.8	2.1
712	6.5	0.9	8.7	1.2	10.1	1.4	9.4	1.6	11.0	1.9
713	5.5	0.7	8.6	1.9	10.1	2.3	8.3	1.7	9.9	2.1
714	10.3	0.8	11.8	1.1	13.8	1.3	11.5	0.8	13.4	0.9
901	7.9	1.1	9.1	0.9	10.7	1.1	9.3	1.2	10.9	1.4
902	7.6	1.1	9.3	1.2	10.9	1.4	9.1	1.6	10.7	1.8
903	7.6	1.0	10.2	0.8	11.9	0.9	10.5	1.0	12.2	1.2
1001	7.3	2.4	7.8	1.4	9.0	1.6	9.3	0.7	10.8	0.8
1002	8.0	0.7	11.2	0.7	13.0	0.8	11.2	0.7	13.1	0.9
1003	8.6	0.7	10.8	0.7	12.7	0.9	10.4	0.7	12.2	0.9
1004	7.9	1.3	10.8	1.0	12.6	1.1	10.2	0.7	12.0	0.8
1005	8.5	1.0	10.8	0.9	12.7	1.1	10.8	1.0	12.6	1.1
1006	8.9	1.1	10.7	0.9	12.5	1.1	10.0	1.0	11.8	1.2
1007	7.8	0.9	10.4	0.7	12.1	0.8	10.7	1.1	12.5	1.3
1008	7.4	1.5	8.4	0.7	9.9	0.9	8.7	1.1	10.3	1.3
1009	7.4	1.4	8.3	0.7	9.8	0.8	8.2	1.1	9.7	1.5
1010	8.7	1.0	10.6	0.9	12.5	1.1	10.1	0.9	11.9	1.1
1011	7.9	1.0	9.5	1.3	11.1	1.5	9.1	1.1	10.7	1.3
1012	6.1	0.9	7.5	0.7	8.8	0.8	7.4	0.7	8.7	0.8
1013	8.0	1.1	9.3	1.0	11.0	1.2	9.3	1.5	11.0	1.7

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$	$\bar{X}$	$\bar{s}$
	-------------------	-------------------	-------------------	-------------------	Mg/ha	-------------------	-------------------	-------------------	-------------------	-------------------
1014	5.8	0.7	7.5	0.7	8.8	0.9	7.6	1.4	9.0	1.7
1015	8.2	1.6	10.8	2.1	12.8	2.5	9.4	1.1	11.1	1.3
1016	6.3	1.0	7.6	1.1	8.9	1.3	7.6	1.3	8.9	1.6
1017	6.0	0.8	7.5	1.0	8.8	1.1	7.5	0.8	8.7	1.0
1018	7.3	1.4	8.8	1.6	10.3	1.8	8.1	1.2	9.1	0.9
1019	7.5	0.8	10.7	0.6	12.5	0.7	10.5	0.9	12.4	1.0
1020	7.5	0.9	9.6	1.8	11.2	2.1	10.6	2.3	12.3	2.7
1021	8.0	1.3	9.2	1.0	10.8	1.1	9.6	1.3	11.2	1.6
1022	7.6	1.5	9.5	1.8	11.1	2.1	9.7	2.0	11.4	2.4
1023	8.8	1.4	9.6	1.1	11.2	1.2	9.6	0.9	11.3	1.0
1024	7.7	0.8	9.6	1.0	11.2	1.2	10.3	1.6	12.0	1.9
1025	7.4	1.0	9.6	0.9	11.3	1.1	11.2	2.3	13.2	2.7
1026	8.5	0.8	10.1	0.7	12.1	1.1	11.1	2.0	12.8	2.2
1027	7.5	0.9	9.6	1.1	11.3	1.3	9.9	1.7	11.7	1.8
1102	7.5	0.8	10.6	0.9	12.6	1.0	10.6	1.0	12.4	1.1
1103	9.0	1.0	10.9	1.6	12.8	1.9	11.8	3.1	14.1	3.6
1104	9.0	1.4	11.2	1.1	13.3	1.3	13.0	3.4	15.4	4.0
1107	10.6	2.3	10.5	1.8	12.1	2.0	11.3	2.8	13.7	3.8
1108	5.1	0.8	7.2	1.2	8.5	1.4	7.2	1.5	8.5	1.7
1301	7.2	0.7	9.8	0.9	11.7	1.2	9.3	0.8	11.1	1.0
1302	6.0	1.0	7.9	1.7	9.3	2.1	7.9	1.6	9.1	1.9
1303	8.0	2.3	10.9	2.9	12.9	3.5	12.7	3.9	15.1	4.5
1305	8.1	2.7	8.8	2.2	10.2	2.6	9.0	2.5	10.7	2.9
1306	6.8	1.6	7.4	1.9	9.3	2.4	10.7	2.9	12.7	3.5
1401	7.8	0.7	10.5	1.1	12.2	1.3	10.7	0.9	12.5	1.0
1402	8.2	0.9	11.2	1.0	13.1	1.2	11.5	1.0	13.5	1.2
1403	8.6	1.0	11.1	0.5	13.1	0.7	11.2	1.1	13.2	1.2
1404	6.0	0.9	8.9	1.7	10.6	2.1	7.9	1.4	9.5	1.6
1405	8.9	0.7	11.6	0.8	13.6	0.9	10.9	1.0	12.8	1.2
1406	10.8	1.1	13.0	0.8	15.3	1.1	11.7	0.9	13.9	1.2
1407	11.3	1.2	12.6	0.4	15.0	0.5	12.9	1.2	15.4	1.4
1408	6.2	1.2	7.3	1.2	8.7	1.4	6.5	1.2	7.7	1.4
1501	12.8	4.2	13.2	2.4	15.8	2.8	13.1	3.1	15.6	3.6
1502	11.9	3.1	13.6	1.7	16.3	2.0	13.8	3.1	16.6	3.6
1503	14.8	5.2	12.4	3.4	15.6	4.0	12.4	3.5	15.0	4.2
1504	4.2	0.9	6.7	1.9	8.1	2.4	7.3	2.2	9.2	3.0
1505	14.7	3.8	17.3	4.9	20.6	5.8	14.5	4.9	17.3	5.6
1506	14.3	4.0	15.8	3.7	18.8	4.4	16.1	3.9	19.1	4.4
1507	15.0	4.8	13.5	4.0	16.4	4.6	13.3	4.0	15.8	4.5
1508	13.0	3.0	16.9	4.3	20.0	4.9	13.9	4.0	16.7	4.5
1601	10.9	0.9	12.7	0.8	14.9	1.0	11.9	1.0	14.0	1.2
1602	10.0	1.0	11.9	0.7	14.1	0.8	11.7	0.9	13.8	1.0
1603	10.8	1.1	12.6	0.4	15.0	0.5	12.1	0.6	14.4	0.7
1604	11.1	2.5	11.6	3.3	12.0	4.0	13.1	4.0	13.6	5.0
1605	9.4	2.6	8.9	2.2	9.4	2.7	10.2	2.5	11.3	4.0

USGS Four Digit Basin	Baseline		Hadley (2025-2034)				Hadley (2090 - 2099)			
	$[CO_2]$ = 365		365		560		365		560	
	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$	$\overline{X}$	$\overline{s}$
	---Mg/ha---									
1606	10.0	3.4	9.8	3.5	10.0	4.2	10.0	3.8	10.3	4.6
1701	8.9	0.8	10.2	0.6	11.9	0.8	10.3	0.7	12.1	0.9
1702	10.4	2.0	14.4	3.0	17.1	3.6	13.7	2.6	16.3	3.1
1703	7.0	0.6	12.0	1.8	14.6	2.7	15.8	3.0	18.6	3.6
1704	8.6	1.0	11.7	1.1	13.8	1.3	13.7	2.8	16.2	3.4
1705	11.7	2.5	12.8	2.4	15.2	2.9	14.1	3.1	17.3	3.9
1706	10.4	1.3	10.8	1.4	12.6	1.7	12.7	1.1	14.8	1.4
1707	10.7	0.8	13.6	0.6	16.0	0.7	13.4	1.0	15.7	1.1
1708	11.4	2.1	12.6	2.0	14.4	2.3	13.8	2.8	15.7	3.2
1709	12.0	1.7	14.2	1.3	16.6	1.5	13.9	1.5	16.2	1.7
1710	12.2	1.3	14.2	1.0	16.6	1.2	14.1	1.1	16.4	1.3
1711	10.7	2.0	13.7	2.5	15.8	2.9	14.4	3.3	16.6	3.9
1712	11.5	0.9	13.3	0.7	15.7	0.8	12.8	0.6	15.1	0.6
1801	9.1	2.0	6.4	1.7	7.5	2.0	8.7	2.3	10.7	2.6
1802	5.3	0.7	5.6	1.0	7.1	1.6	5.7	2.4	7.5	3.1
1803	12.9	1.5	11.7	1.7	13.7	2.0	10.7	1.3	12.4	1.3
1804	6.6	1.5	11.6	1.0	14.0	1.1	12.0	1.5	13.8	1.6
1805	10.1	2.5	8.7	2.6	11.0	2.7	9.9	2.1	12.6	1.6
1806	13.1	1.4	12.7	1.4	15.0	1.7	12.9	1.6	15.4	1.8
1807	17.7	3.4	16.0	2.9	18.8	3.3	14.9	2.8	17.5	3.1
1808	6.7	1.3	6.7	1.4	7.8	1.6	9.4	1.6	11.0	1.9
1809	10.2	2.3	10.5	1.9	12.8	2.3	9.2	1.5	11.4	1.7
1810	15.2	5.1	16.8	4.9	19.1	5.5	12.9	4.4	15.6	5.0